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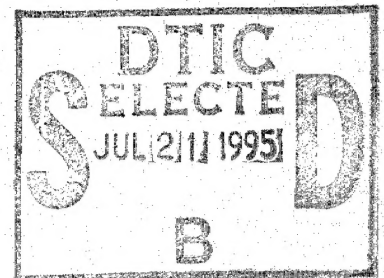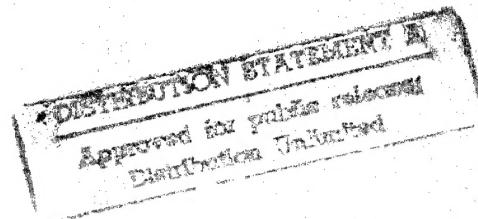
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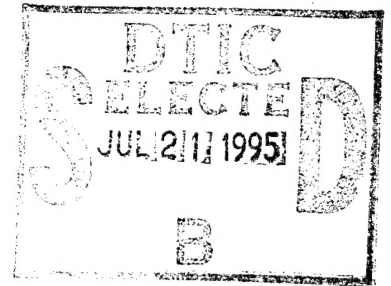
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ABSTRACTS OF PAPERS

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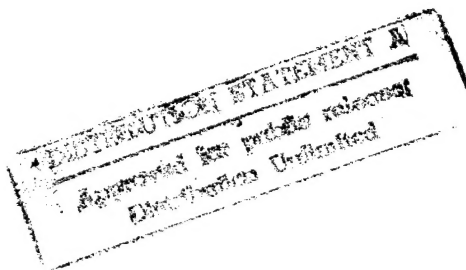Woods Hole Oceanographic Institution

Woods Hole, Massachusetts

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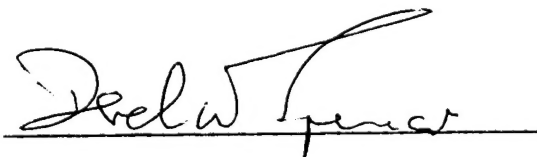reference should be followed by the phrase:
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PREFACE

This volume contains all abstracts submitted for publication during calendar year 1982 by the staff and students of the Woods Hole Oceanographic Institution. Because some of the abstracts may not be published in the journal to which they have been submitted initially, we have purposely omitted identifying the journals. The volume is intended to be informative, but not a bibliography.

The abstracts are listed by title in the Table of Contents and are grouped into one of our five departments, marine policy, or the student category. An author index is presented in the back to facilitate locating specific papers.

Derek W. Spencer
Associate Director for Research

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CONSTITUTIVE LEVELS AND INDUCTION OF HEPATIC ARYL HYDROCARBON HYDROXYLASE ACTIVITY DURING EMBRYONIC DEVELOPMENT IN BROOK TROUT

Robert L. Binder and John J. Stegeman

Levels of aryl hydrocarbon hydroxylase (AHH) activity were determined in liver homogenates of brook trout embryos, eleutheroembryos and yearlings. Hepatic AHH specific activity was about 3-fold higher in eleutheroembryos at both 9 and 33 days from hatching than in embryo 5 days prior to hatching. Specific activity was essentially the same in liver homogenates from brook trout embryos and yearlings. A similar pattern emerged when hepatic AHH activity was normalized to body weight. Levels of AHH activity in homogenates of liver from embryos exposed for 21 days to Aroclor 1254 at 0.75 and 7.5 ppm in the embryo body and assayed approximately 5 days before hatching were induced 4 fold above the activities in control embryos. The lack of an observed dose dependency suggests that the induced levels of activity represent the maximal extent of the response in these trout embryos. The presence of substantial mono-oxygenase activity during late embryonic development in fish may facilitate the elimination of lipophilic xenobiotics present in the yolk, but may also contribute to the formation of activated metabolites and toxic lesions.

PHYSIOLOGICAL AND BIOCHEMICAL ASPECTS OF CRUSTACEAN DEVELOPMENT AND METAMORPHOSIS

Judith M. Capuzzo

Successful development and metamorphosis of the larval stages of marine crustaceans are dependent on the balance and efficient utilization of energy reserves, with lipids being of either primary or secondary importance in energetics of crustacean development. Recent studies suggest that changes in metabolic activity during larval development of several crustacean species cannot be explained by a simple body size relationship. Changes in lipid content and lipid utilization have been detected during development from embryonic to larval to postlarval stages and reflect the transition in energy utilization and storage patterns.

The greatest increases in metabolic demand and shifts in biochemical composition occur in pre-metamorphic stages. Cyclical changes in physiological and biochemical parameters are evident within the molt cycle and suggest that metabolic processes as well as morphological changes may be under endogenous hormonal control. Comparative aspects of energetics in crustacean larvae will be discussed with specific emphasis given to the decapod crustaceans.

PHYSIOLOGICAL AND BIOCHEMICAL ASPECTS OF EMBRYONIC AND LARVAL DEVELOPMENT OF THE WINTER FLOUNDER, Pseudopleuronectes americanus WALBAUM

Catherine M. Cetta and Judith M. Capuzzo

Eggs and larvae of the winter flounder were hatched and raised in the laboratory under controlled conditions. Biochemical composition was measured through development and found to be similar to that of other species: 65 to 80 percent protein, 15 to 30 percent fat, and 0 to 5 percent carbohydrate. Ash content was 7 to 10 percent of dry weight. The sequence of utilization of these components appears to be carbohydrate and then protein to hatching, lipid, mixed lipid and protein, then predominantly protein until feeding begins. Carbohydrate is accumulated at first feeding and depleted when growth begins. Protein and lipid are deposited in approximately constant proportions. The chorion makes up more than half of the weight of an egg and the data suggest that it is possibly a source of nutrition to the developing embryo.

Respiration rates of eggs were low, $0.002 - 0.015$ μl O_2 egg^{-1} h^{-1}, but rose gradually from fertilization to hatching. Respiration rates of early larvae were from two to eight times that of eggs ($0.033 - 0.131$ μl O_2 larva^{-1} h^{-1}). Variation in larval respiration rates indicated a three-fold difference in rate according to level of activity. Eggs excreted ammonia at an increasing rate from fertilization to hatching. Larvae excreted ammonia, primary amines, and other unidentified organic nitrogenous substances. Rates of excretion and proportions of excretory products vary with stage of development. Primary amine excretion is variable and a major component in early stages. Ammonia-N excreted was two to 20 times primary amine N excreted. Unidentified substances were the predominant form of N excretion during early feeding. Ammonia accounted for most of the N excreted in older larvae.

Conversion efficiency for eggs is 59 percent. Net caloric conversion and net and gross nitrogen efficiencies are low in first feeding larvae compared to adult fishes (32.2 percent, 27.7 percent, and 10.7 percent respectively). Early specific growth rates were 2.1 percent and 5.5 percent. Growth may be limited by enzymatic inefficiency in early stages.

PATTERNS OF BENZO(A)PYRENE METABOLISM BY VARIED SPECIES, ORGANS AND DEVELOPMENTAL STAGES OF FISH

John J. Stegeman, Bruce R. Woodin and Robert L. Binder

Microsomal preparations of liver from adults of several (teleost) fish species, including scup (Stenotomus chrysops), winter flounder (Pseudopleuronectes americanus) and killifish (Fundulus heteroclitus), were found to metabolize the model polycyclic hydrocarbon carcinogen benzo(a)pyrene with a marked regiospecificity, forming high percentages of benzo-ring derivatives, but particularly BP-7,8-dihydrodiol and BP-9,10-dihydrodiol. The identity of these products was confirmed by mass spectrometry of metabolites formed by scup (S. chrysops) liver microsomes compared to the spectra obtained for authentic trans-dihydrodiols. Whereas the benzo-ring dihydrodiols equalled 40-60 percent of the total ethyl acetate-soluble metabolites formed by liver microsomes of the various species, the K-region metabolite BP-4,5-dihydrodiol was formed in amounts that were small or undetectable. Microsomal preparations of kidney and gill from S. chrysops formed BP-7,8-dihydrodiol and BP-9,10-dihydrodiol in proportions like those seen with liver of the same species. Embryonic tissues of Fundulus heteroclitus metabolized BP with a regiospecificity similar to that exhibited by adult liver microsomes. Isomeric forms of BP-7,8-dihydrodiol are potent proximate carcinogens and activation of BP to mutagenic and carcinogenic derivatives is associated with metabolism on the benzo-ring of BP. The widespread appearance of regio-specificity for this portion of the BP molecule suggests that fish may be useful models for the study of other factors that might affect tumorigenesis by polycyclic hydrocarbons.

A Q U A C U L T U R E

NITROGEN ALLOCATION AND STORAGE PATTERNS IN Gracilaria tikvahiae (RHODOPHYTA)

Kimon T. Bird, Clifford Habig and Thomas DeBusk

Internal nitrogen pools in thalli of Gracilaria tikvahiae McLachlan were examined in three experiments as a function of total nitrogen content of the thallus, nitrogen deprivation, and nitrogen resupply. Amino acids and proteins appeared to form the major nitrogen storage pools in G. tikvahiae, while DNA appeared to be relatively unimportant in this regard. Inorganic nitrogen in the forms of NH_4^+ and NO_3 was found in the thalli; however, its contribution to the total nitrogen pools was small. Within the protein pool, the phycoerythrin pigments appear important as a source of nitrogen when thalli are initially becoming nitrogen limited. In general, there was an inverse relationship between the levels of nitrogen and the carbohydrate content of the algal thalli.

CALORIMETRIC DIETARY EVALUATION IN THE AMERICAN LOBSTER

Dale F. Leavitt

Dietary evaluation is a unique problem in crustacean research due to the incremental growth pattern characteristic of animals that molt an exoskeleton. To circumvent traditional growth trial methods for diet evaluation, calorimetric techniques adapted from animal agriculture have been applied to dietary studies in the adult American lobster (Homarus americanus). Utilizing nutrient and energy balance studies in association with either direct or indirect calorimetry, the time required to evaluate the efficicacy of formulated diets can be greatly reduced. Three experimental diet formulations (of varying protein:energy

ratio or cholesterol level) were compared to a control diet of whole herring (Clupea harengus). No differences were found in rate of weight gain among the 4 groups of lobsters during a 60-day feeding trial. The same 4 diets were tested using calorimetric techniques in a 4x4 Latin-square feeding trial. Using these techniques, differences were noted in the utilization of nutrients and energy from the 4 diets. A comparison of direct and indirect calorimetric techniques was also made.

Published in: American Zoologist, 1982.

Supported by: WHOI.

THE ROLE OF INTRODUCED BIVALVE MOLLUSC SPECIES IN MARICULTURE: PAST, PRESENT, AND FUTURE

Roger Mann

Premeditated introductions of non-indigenous molluscan shellfish species have been important in establishing several substantial fisheries. The North American fishery for Crassostrea gigas developed from active introductions that began in the early part of this century and continued until 1978. More recently C. gigas has been introduced to many sites in Europe, South Africa, South America, the Mediterranean, and the Indian and Pacific Oceans. The European Flat Oyster, Ostrea edulis, has been successfully introduced to the state of Maine. An international code of practice for examining and effecting intentional introductions has been developed which recommends a combination of quarantine procedures and hatchery rearing to avoid accidental introduction of associated species and disease organisms. Several nations have developed comprehensive legislation to control movement of non-indigenous species. Active movement of species for culture purpose continues, especially in Europe and the Pacific Islands.

Supported by: NOAA Sea Grant NA80AA-D-00077.

WHOI Contribution No. 5277.

ON THE SELECTION OF AQUACULTURE SPECIES: A CASE STUDY OF MARINE MOLLUSCS

Roger Mann

An overview of marine mollusc culture reveals a rich variety of species in culture, physical environments where culture is effected, and technological, social and economic backgrounds of the participating individuals. Despite this variety a few basic criteria have, until recently, dictated which molluscan species are prime candidates for aquaculture. It is the purpose of this paper to illustrate how innovative thinking has influenced the historical development of mollusc culture and how advancing culture technology has, and potentially will, influence the future choice of prime aquaculture species.

The criteria for selection of aquaculture species, first documented by Fan Lee nearly 2,500 years ago in a treatise devoted to pond culture of freshwater fishes, stated that high priority should be given to species that are tasty, grew rapidly, not cannibalistic, hardy and inexpensive to culture. It was not until the present century that more intensive or extensive culture efforts focused the need to append this list to include adequate availability of seed from natural sources and good market value of final product. Two, somewhat unrelated efforts were, however, to provide additional options for present and future efforts in molluscan culture. Both efforts gained momentum during the early decades of this century. The first effort was the establishment of a reproducing population of Crassostrea gigas on the northwest coast of the North American continent through active introduction of breeding stock. The second effort was the development of controlled or manipulated environment hatcheries for seed production, mostly of oysters and mostly on the U.S. east coast. In combination these resulted in the aquaculturist being able to choose a candidate species from a global rather than local endemic pool and to uncouple the problem of seed or juvenile stock availability from natural biological fluctuations and seasonality. We are now able to raise and maintain, through one or more generations, species which have only a marginal rating by Lee's original criteria but which command high market prices from natural fisheries. A dichotomy in future development is evident. Where the primary stimulus is large volume production for consumption purposes, through a combination of intensive juvenile production and extensive grow out methods, then an appended listing of Lee's criteria is applicable irrespective of the economic and social background of the group being served. In contrast, where the primary stimulus is economic and focuses on the culture of one of the aforementioned marginally appropriate but highly priced species, then equal or greater consideration must be given to the biological, engineering and financial limitations of culturing large numbers of seed to adult size in a controlled environment.

In press: Proceedings of Symposium entitled "Recent Innovations in Cultivation of Pacific Molluscs", editors: D. Morse, K. K. Chew and R. Mann, Elsevier.

E S T U A R I N E / R I V E R   E C O S Y S T E M S

A COMPARISON OF BENTHIC COMMUNITY METABOLISM IN FOUR STREAM SYSTEMS: A TEST OF THE RIVER CONTINUUM HYPOTHESIS

Thomas L. Bott, James T. Brock,
Cynthia S. Dunn, Robert J. Naiman,
Roger W. Ovink and Robert C. Petersen

Benthic community metabolism was studied on stream systems located in four different biomes of the United States (White Clay Creek-Buck Run, Pennsylvania; Augusta Creek-Kalamazoo River, Michigan; Salmon River, Idaho; McKenzie River, Oregon). Annual means (in $gD.O.\cdot m^{-2}\cdot day^{-1}$) for gross primary productivity ranged from 0.16 to 3.37, for benthic community respiration from -0.36 to -2.88 and for net daily metabolism (the difference between the two) from -0.73 to +0.50. Primary productivity and community respiration both increased with downstream direction on all systems. The reach (designated 1-4 in order of increasing size) where autotrophy first predominated annual metabolism differed between sites; station 1 was heterotrophic at all sites; autotrophy predominated by station 2 at Idaho, station 3 at Oregon, and station 4 at Michigan. At Pennsylvania all reaches but station 3 were heterotrophic; photosynthesis dominated only slightly at station 3. Results confirmed the hypothesis of a predictable trend in community metabolism from heterotrophy to autotrophy with downstream direction, but the furthest downstream reach was not necessarily the most autotrophic. About half of the reaches that were heterotrophic annually were autotrophic at one or more seasons. Autotrophy predominated most often at Idaho and heterotrophy at Pennsylvania. Eastern stations (and sometimes Idaho) usually had high metabolic rates and Oregon stations almost always low rates. Parameters accounting for most variance in multiple linear regression analyses of the combined data describing metabolic variables were factors related to stream size, light, temperature and chlorophyll a concentration. These factors, along with water hardness, nitrogen and phosphorus concentrations were the factors most important in differentiating between sites.

In press: Ecological Monographs.

COMPARISONS OF THE PROCESSING OF ELEMENTS BY ECOSYSTEMS: II METALS

Anne E. Giblin

In searching for safe cost-effective ways to dispose of sewage, increasing attention has been focused on disposal into natural ecosystems such as wetlands. Metals are important contaminants in sewage and sludge and it is necessary to understand their movement in these ecosystems before the relative merits of wetland disposal schemes can be fully evaluated. Since wetland sediments are usually high in organic matter, and frequently contain sulfides, it has been suggested that wetland sediments should be expected to retain heavy metals. Factors which might be expected to reduce metal retention in wetland ecosystems such as low sediment pH's are often overlooked.

Fluxes of metal through pristene wetlands and those receiving sewage may be quite high and vary greatly between metals. In the small number of studies where metal fluxes through wetlands has been measured, as much as 50 percent - 100 percent of the Zn, Cu, Cd, and Hg entering the wetland was subsequently lost from the system. Retention of Fe, Mn, and Pb was higher and loses range from 0 percent - 50 percent. When metal loading is increased by the addition of sewage or dredge spoil waste the percentage of metal retained by the wetland decreased for all metals except Hg.

CHARACTERISTICS OF SEDIMENT AND ORGANIC CARBON EXPORT FROM PRISTINE BOREAL FOREST WATERSHEDS

Robert J. Naiman

Estimates of the amount of material moving annually from terrestrial ecosystems to the ocean are largely based on an incomplete understanding of events occurring throughout the hydrologic year, and only a vague comprehension of in-stream processes controlling that export. This study describes sediment and organic carbon export throughout the annual hydrologic cycle from five pristine watersheds in the boreal forest of Quebec, Canada. Discharge, suspended sediment, particulate organic matter ($\delta 1.5$ μm), and dissolved organic carbon (1.5 μm diameter), and the percentage of organic matter were measured from 1979 to 1981 in First Choice Creek (1st order; watershed area: 1.25 km^2), Beaver Creek (2nd order; 1.83 km^2); Muskrat River (5th order; 214 km^2), Matamek River (6th order; 673 km^2);

and the Moisie River (9th order; 19,871 km^2). All streams, with the exception of First Choice Creek, have a strong spring freshet when 43 to 55 percent of the annual discharge occurs. During this two month period 71 to 92 percent of the annual sediment load is exported but only 59-65 percent of the annual POM load and only 47-51 percent of the annual DOC load. Sediment yield is relatively constant between watersheds (1.5-7.6 g·m^{-2}·yr^{-1}), as is POM export (1.0-6.7 g AFDW·m^{-2}·yr^{-1}); however, export DOC varies from 3.1 g C·m^{-2}·yr^{-1} in First Choice Creek to 48.4 g C·m^{-2}·yr^{-1} in Beaver Creek. There appears to be rapid loading of carbon between 1st and 2nd order streams in boreal forests, followed by biological and physical processing as watershed area increases. Thus, for the Moisie River watershed, export of TOC is reduced to only 4.7 g C·m^{-2}·yr^{-1}. Export of coarse particulate organic matter (>1 mm) is negligible (normally <0.1 mg L^{-1}), as is oxidation of the suspended load (<0.5%·d^{-1}). Effects of summer storms, natural diel variations, and depth of sample from the water column have a minimal influence on concentrations. Rating curves (kg·d^{-1} vs. discharge) are developed to estimate the annual yield of sediment, POM, and DOC. Results suggest that in-stream processing and retention devices exert considerable control over the quantity and nature of organic material carried downstream. Physical processes such as the discharge regime and stream power are relatively less important in determining organic concentrations but more important in determining sediment concentrations.

A GEOMORPHIC APPROACH FOR EXAMINING THE ROLE OF PERIPHYTON IN LARGE WATERSHEDS

Robert J. Naiman

Geomorphic analysis of watersheds, when combined with biotic studies of specific ecosystem components, place these components in a proper ecosystem perspective. In undisturbed boreal forests of Quebec, Canada, annual periphyton can be reliably predicted from stream order and extrapolated to the watershed level when combined with some simple geomorphic analyses. At the watershed scale periphyton contributes only 11 to 27 percent to total ecosystem metabolism, depending on the size of the watershed. The most metabolically active components are fine particulate organic matter (0.5 μm - 1 mm) and mosses.

THE INFLUENCE OF STREAM SIZE ON THE FOOD QUALITY OF SESTON

Robert J. Naiman

During 1979 and 1980, suspended particulate material (seston) was examined for potential food quality in five streams ranging in size from 1st to 9th order in Quebec. Seston was wet sieved into CPOM (>1 mm), FPOM (53 μm-1 mm), and VPOM (0.5-53 μm) and examined for the relative contribution of each size class to the total mass, the percentage of organic matter, the carbon-to-nitrogen ratio, the amount of chlorophyll a, and the respiration rate of associated microbes. In streams >2nd order VPOM constituted >90 percent of the total mass. The percentage of organic matter ranged from 4? to 64 percent for CPOM, 21 to 35 percent for FPOM, and 32 to 82 percent for VPOM. During summer the majority of chlorophyll was associated with FPOM and CPOM, but most values were <5 mg Chl a/g AFDM. Depending upon the stream, chlorophyll bearing particles constituted 6 to 34 percent (x=15.1 percent) of the seston load. Highest respiration rates were associated with VPOM, nearly an order of magnitude greater than FPOM or CPOM. Carbon-to-nitrogen ratios decreased with particle size for all streams, and the lowest ratios and highest percentage of nitrogen were found in the large rivers. A scanning electron microscope was used to examine the nature of particles and relative degree of microbial colonization in each stream. The data suggest that the apparent food quality of seston increases to some extent downstream, thereafter declining as biological processing proceeds. The influence of consumer organisms on drifting particles was apparent with the nature of the seston changing markedly in a downstream direction.

PERIPHYTON ACCUMULATION RATES IN FIVE BOREAL FOREST RIVERS OF QUEBEC

Robert J. Naiman

Measurements were made in the Moisie, Matamec, Pigou, Tortue, and Manitou rivers to assess river-to-river variability in summer periphyton production. By quantita-

tively examining periphyton accumulation on plexiglas plates over three-week periods, it was concluded that average river-to-river variability in production parameters may exceed 100 percent for rivers with apparently similar physical and chemical characteristics. Correlations between biological parameters and physiochemical variables were often significant, but not consistent between sites. Of the five rivers, the standing crop of chlorophyll (mg Chl $\underline{a}$/m^2) is significantly greater in the Matamec River, while the concentration of chlorophyll $\underline{a}$ per gram ash-free-dry-weight (mg Chl $\underline{a}$/$\underline{g}$ AFDW), and the accumulation rate of organic matter (g AFDW $\cdot$ m^{-2} $\cdot$d^{-1}) are statistically similar for all rivers.

In press: Le Naturaliste Canadien.

F I S H

MESOPELAGIC FISHES IN GULF STREAM COLD-CORE RINGS

Richard H. Backus and James E. Craddock

Calculations of abundance of midwater fishes in the families Myctophidae, Gonostomatidae, Photichthyidae, and Sternoptychidae for the 1000 m water column were made in cold-core rings and in the nearby Sargasso Sea and Slope Water. The data were considered with respect to the depth to 15°C, which isotherm lies shallow in the Slope Water, deep in the Sargasso Sea. Myctophid-gonostomatid biomass (excluding Cyclothone spp.) varied inversely as the depth to 15° with that for the Slope Water in the ratio of about 4.5:1 to that for the northern Sargasso Sea. For Cyclothone spp. the ratio was about 2.5:1. Benthosema glaciale, a subpolar-temperate myctophid, becomes more and more restricted to the deep part of aging rings and finally disappears from them. Warm-water fishes quickly become abundant in the upper few hundred meters of aging rings. The myctophids Lampanyctus crocodilus, L. pusillus, and Hygophum benoiti appear to be rings exploiters; they were more abundant there than elsewhere. Detrainment of fish from Ring "Frank" was observed at depths near 600 m. Three-month old Ring "A1" already had entrained fish at depths greater than 250 m. The northern edge of the Gulf Stream, an important faunal boundary between temperate and subtropical parts of the western Atlantic, is a differential barrier; warm-water animals cross it to the north more easily than do cold-water animals to the south.

ABUNDANCE AND DISTRIBUTION OF Salmincola edwardsii (COPEPODA) ON ANADROMOUS BROOK TROUT, Salvelinus fontinalis IN THE MOISIE RIVER SYSTEM, QUEBEC

Geoff A. Black, W. Linn Montgomery and Frederick G. Whoriskey

Riviére á la Truite, a tributary of the Moisie River, is probably a focus of S. edwardsii transmission within the system. Differences in prevalence of the copepod on fish between Riviére á la Truite and the main river suggested that up to 41 percent of anadromous brook trout in the Moisie River system overwinter in the tributary. Infected fish were generally less than 200 mm long and copepods were attached almost exclusively to the fins and their bases. The primary site of copepod attachment at low intensities of infection was the adipose fin but at high intensities the dorsal fin was most frequently infected. This displacement in attachment location with increased intensity may result in density-dependent mortality of copepods. Copepods were overdispersed on the host population at each major sampling time and data fit a negative binomial distribution (k ranged from 0.2-0.8).

In press: Journal of Fish Biology.

SPRING MIGRATORY SYNCHRONY OF SALMONID, CATOSTOMID AND CYPRINID FISHES IN THE LOWER MOISIE RIVER, QUEBEC

W. Linn Montgomery, Stephen D. McCormick, Robert J. Naiman, Frederick G. Whoriskey, Jr. and Geoff A. Black

In May-June 1980, six species of fishes exited Riviére á la Truite, the major tributary of the lower Moisie River, Quebec, in a highly synchronized emigration. Species included: longnose sucker (Catostomus catostomus), white sucker (C. commersoni), lake chub (Couesius plumbeus), juvenile sea

lamprey (Petromyzon marinus), Atlantic salmon (Salmo salar) parr and smolt, and anadromous brook trout (Salvelinus fontinalis). Emigration for all except the lamprey began on 27 May and ended by 9-11 June; lamprey movements began on 4-5 June and peaked on 10 June. Patterns in daily catches, taken to reflect migratory activity, differed between the cyprinoids (suckers, chub) and salmonids. The suckers and chub exhibited 3-4 peaks of activity, each separated by approximately three days from other peaks, and each peak smaller than the previous. Salmonids showed no periodicity in activity, and catches per day increased as the run progressed. Onset of the run coincided with dropping water levels and discharge, but neither temperature, discharge nor tides seem sufficient to explain the periodic behavior of the suckers and chub. The migratory synchrony of five species and the periodicity in activity of three species suggest that interspecific social interactions may play important roles in cueing and structuring multispecies movements of fishes.

In press: Canadian Journal of Zoology.

SEX AND EXPLOITATION: LIFE HISTORY RESPONSES OF MALE AND FEMALE ATLANTIC SALMON TO RECENT SEVERE MORTALITY

W. Linn Montgomery and
Robert J. Naiman

Atlantic salmon from the Matamek River, North Shore of the St. Lawrence, Quebec, experience heavy mortality at sea but are undisturbed within the river. Life history responses since 1967 to high-seas mortality include changes in the age and sex structure of adult and smolt populations, and in the body size, sex ratios, and frequency of precociously mature males among premigratory parr. Males are exhibiting rapid shifts in life history relative to females and a greater plasticity in mating behavior than females.

INFLUENCE OF RIPARIAN VEGETATION AND WOODY DEBRIS ON THE ECOLOGY OF BROOK TROUT FRY, Salvelinus fontinalis

Roderick Morin, Robert J. Naiman
James A. Gustin and Robert B. Dubois

Riparian vegetation and woody debris were experimentally removed from equal sections of the Matamek River, Quebec, to test hypotheses relating to habitat preferences of brook trout fry. Analyses of abundance and spatial distribution of trout fry indicate that fry selected denuded areas during late June and early July, being distributed in shallow water (<10 cm) close to the river edge. When fry were in association with riparian vegetation, they were located in deeper water at the edge of the riparian zone. Trout fry were distributed close to the water surface early in the summer, progressively moving downward and away from the river edge over time in all habitat treatments and reference areas. Growth and feeding were similar between habitat treatments. Observations on trout fry behavior in the experimental area of the Matamek River and in a smaller stream, Riviére á la Truite, led us to alternative hypotheses of habitat utilization based on the role of social organization - specifically, territoriality and dominance hierarchy - in regulating the degree of association between fry and available habitat.

MARINE MAMMALS

THE INTERNAL MECHANISM OF RORQUAL FEEDING

Richard H. Lambertsen

This study elucidated the internal mechanism that enables rorquals (Balaenopteridae) to engulf a large volume of water prior to filtering it for prey. Anatomic experiments and observations were made on specimens of Balaenoptera acutorostrata, B. borealis, and B. physalus to assess the dynamic relationships of the tongue, nonlingual intermandibular lining, and cavum ventrale (a tissue cleft beneath the grooved, ventral body wall) as they would occur during engulfment. With the mouth empty, a distinct, centrally furrowed tongue was present in all three species. The nonlingual intermandibular lining ran outwards from the root of the tongue to attach along the ventral border of the mandibles. The cavum ventrale extended anteriorly beneath

the tongue and non-lingual intermandibular lining from the cervico-thoracic region. By simple manipulation, the tongue could be transformed into a hollow, sac-like structure invaginating the cervical portion of the cavum ventrale. During this transformation, the non-lingual intermandibular lining was stretched posteriorly to completely cover the floor of the mouth. When the mouth of a suspended B. acutorostrata specimen (head only) was filled with water to simulate engulfment, the everted tongue and non-lingual intermandibular lining expanded through the transected space of the cavum ventrale, to form a capacious "oral sac." The posterio-dorsal wall of this sac was formed by what had been the tongue. Adaptations that enhance the expansibility of the oral sac include a highly elastic connective fiber matrix and a redundant surface created by epithelial corrugations and the tongue's central furrow. It is concluded that 1) during engulfment the tongue would initiate distension of the cavum ventrale by everting between the cavum's inner and outer walls, 2) the everted, elastic tongue would act to enlarge the capacity of the mouth, and 3) the sac lining the cavum ventrale at the end of engulfment would be created by the tongue and non-lingual intermandibular lining.

In press: Journal of Mammalogy.

Supported by: Coastal Research Center.

WHOI Contribution No. 5034.

MESOPELAGIC FISHES EATEN BY FRASER'S DOLPHIN, Lagenodelphis hosei

Bruce H. Robison and James E. Craddock

Examination of the stomach contents of three specimens of the rare, pantropical dolphin, Lagenodelphis hosei, showed them to have been feeding on a mixed diet of mesopelagic fishes, shrimps and squids, with fishes by far the most important component. Ecologically and morphologically the prey fishes comprised three types: a group of elongate, solitary, vertically mobile species; deep-bodied, aggregative, non-migratory fishes; and thick-bodied, dark colored non-migrators. Based on the known vertical distribution patterns of the prey species, the three dolphins had been feeding at depths between 250 and 500 m. The large sizes and species composition of the prey fauna indicate that the dolphins were feeding selectively, ignoring the smaller, more abundant vertically migratory species which dominate the upper mesopelagic midwater fish fauna of the eastern tropical Pacific. The estimated nutritional value of the ingested prey is similar to the values reported for related cetaceans maintained in captivity.

In press: Fisheries Bulletin.

Supported by: NSF Grants DES74-23209 and OCE78-09018.

WHOI Contribution No. 5148.

TOWNSEND'S UNMAPPED NORTH ATLANTIC RIGHT WHALES (Eubalaena glacialis)

William E. Schevill
and Karen E. Moore

Townsend's detailed maps of worldwide whale distribution from XIXth Century American whaling logbooks (1935, Zoologica, N.Y., 19: 1-50) omitted his North Atlantic records for Eubalaena. We have read twelve of his fifteen sources and have mapped the right whales therein recorded.

In press: Breviora.

Supported by: ONR Contract N00014-82-C0019 NR 083-004.

WHOI Contribution No. 5241.

RADIO TAGS FOR WHALES - CHARACTERISTICS OF AN IDEAL TAG

William A. Watkins

Efforts to develop radio tags for whales have continued since 1961 with considerable experimentation in the design and field testing of attachments, transmitters and receiving systems. Two types of tags have been utilized most: the WHOI/OAR tag which is implanted remotely (at 30 m) within the blubber with only the antenna external, and the Mate/Telonics tag that is external to the skin but is attached (at 5 m) with "umbrella stake" fasteners into the blubber. From the experience with all these tags on right whales, finbacks, humpbacks, Bryde's whales, bowheads, and gray whales, 12 characteristics of an ideal tag are derived and discussed.

In press: Conference on Biology of Bowhead Whales, Anchorage, Alaska, January 25-29, 1982.

Supported by: ONR Contract N00014-82-C-0019 NR 083-004; BLM Contract AA851-CTO-23.

WHOI Contribution No. 5097.

OBSERVATION OF THREE RIGHT WHALES
(Eubalaena glacialis)
ALTERNATING AT THE SURFACE

William A. Watkins and Karen E. Moore

Northern right whales (Eubalaena glacialis) have been studied in waters near Cape Cod since 1955 by workers at Woods Hole Oceanographic Institution. In order to assess population numbers, movement, and group composition of this endangered species it is necessary to distinguish individual whales. Patterns of cephalic "callosities" (rough skin patches inhabited by light colored cyamids) have been used for identification. During a flight on 23 April 1981 three right whales of similar size were observed alternating at the surface, each in a repetitive 13-1/2 to 15-minute dive cycle, with only one whale at the surface at a time. Photographs document the presence of three whales. This observation underscores the need for caution in assessing numbers and studying behavior of right whales.

In press: Journal of Mammalogy.

Supported by: ONR Contract N00014-81-C0019 NR 083-004.

WHOI Contribution No. 5166.

AN UNDERWATER ACOUSTIC SURVEY FOR SPERM WHALES (Physeter catodon) AND OTHER CETACEANS IN THE SOUTHEAST CARIBBEAN

William A. Watkins and Karen E. Moore

A survey for sperm whales (Physeter catodon) and other cetaceans was conducted in November 1981 in the southeast Caribbean (61° to 61°30'W, 12°40' to 14°40'N) with underwater and visual assessments. During 69 of 82 listening sessions sperm whale sounds were recorded, similar to sounds from these whales in other areas. From the underwater sounds, the local population of sperm whales was estimated at 200, with 46 to 64 seen at the surface. The whales were found in water depths of 1000 to 3000 m, and dives of an hour or more were made by large and small (calves) animals. The whales were seen in scattered groups of 2-15 or more of mixed lengths (5 to 15 m). Temporally patterned, repetitive click series ("codas") were heard particularly from the larger mixed groups of sperm whales. Other cetaceans also were found and their underwater sounds recorded: Globicephala macrorhynchus, Stenella longirostris, S. clymene, and Delphinus delphis.

Published in: Cetology, 46, 1-7.

Supported by: ONR Contract N00014-81-C-0019 NR083-004.

WHOI Contribution No. 5175.

MARINE POLLUTION

PREDICTING POLLUTION EFFECTS ON ZOOPLANKTON POPULATIONS IN THE MARINE ENVIRONMENT: COMPARISON OF SUBLETHAL STRESS INDICES

Judith M. Capuzzo

In considering the effects of pollutants on zooplankton populations, it is important to ascertain how sublethal responses may affect secondary production and further what role zooplankton may play in the transfer of pollutants to higher trophic levels. The most critical consequences of pollutant exposure to zooplankton populations are the impairment of reproductive potential and disruption in community energetics. These changes are difficult to predict in situ, however, because of the high variability of natural populations and hydrographic conditions. Biochemical and physiological changes that precede population and community changes are more amenable as early warning signals of stress under field conditions and their usefulness in predicting alterations in the energetics of zooplankton populations and the disruption in energy flow through plankton communities warrant further investigation.

In press: H. H. White, ed., Meaningful Measures of Marine Pollution Effects.

Supported by: NOAA Sea Grant NA77AA-D-00027.

PHYSIOLOGICAL EFFECTS OF PETROLEUM HYDROCARBONS ON LARVAL LOBSTERS: HYDROCARBON ACCUMULATION AND INTERFERENCE WITH LIPID METABOLISM

Judith M. Capuzzo and Bruce A. Lancaster

The physiological effects of naturally dispersed and chemically dispersed crude oil-seawater mixtures and ingestion of an oil-contaminated food source on larvae of the American lobster Homarus americanus have been investigated in continuous flow bioassays. Disruption in energetics of larval stages has been observed and correlated with a shift in the normal pattern of lipid utilization. No differences were apparent in the toxic effects of naturally dispersed and chemically dispersed crude oil-seawater mixtures to larval lobsters, indicating that the increased availability of microdroplets of oil in the chemically dispersed suspensions did not influence toxic effects. Larval lobsters fed an oil-contaminated food source showed earlier signs of stress than larvae exposed to oil-seawater dispersions;

however, the later larval stages also showed some restoration of normal energetic patterns during exposure. Hydrocarbon turnover appeared to be rapid and little accumulation of petroleum derived hydrocarbons was observed. The relationship of developmental and energetic abnormalities of larval crustaceans exposed to petroleum hydrocarbons is discussed.

PREFERENTIAL ACCUMULATION OF SEDIMENT-ASSOCIATED VIRUSES FROM THE WATER COLUMN BY EPIFAUNAL AND INFAUNAL SHELLFISH

Edward F. Landry, James M. Vaughn, Thomas J. Vicale and Roger Mann

The present study focused on the importance of contaminated sediments in shellfish accumulation of human viruses. Epifaunal (Crassostrea virginica) and infaunal (Mercenaria mercenaria) shellfish, placed on or in cores, were exposed to either resuspended or undisturbed sediments containing bound poliovirus type 1 (LSc 2ab). Consistent bioaccumulation by oysters (4 of 5 trials) was only noted when sediment-bound viruses occurred in the water column. Virus accumulation was observed in a single instance where sediments remained in an undisturbed state. While the incidence of bioaccumulation was higher with resuspended, rather than undisturbed infected sediment, the actual concentration of accumulated viruses was not significantly different. The accumulation of viruses from the water column was further demonstrated by the isolation of viruses from oysters residing in inoculated sediments. When clams were exposed to undisturbed, virus-infected sediments, two of five shellfish pools yielded viral isolates. Bioaccumulation of undisturbed sediments by these bivalves was considered marginal when related to the concentration of viruses potentially available. The results suggested that virus-contaminated sediments would only represent a significant threat when suspended in the water column. Arguments were advanced for water-column sampling in the region of the water-sediment interface in order to provide an accurate determination of the virological quality of shellfish harvesting waters.

BENTHIC FILTER FEEDING: A NATURAL EUTROPHICATION CONTROL

Charles B. Officer, T. J. Smayda and Roger Mann

The importance of the benthic filter feeding community as a natural control on eutrophication is considered. The important environmental factors favorable for such a control are relatively shallow water depths and a dense benthic filter feeding community of small animals. The criteria are summarized in the equivalence of the water recycling time, T_f' for the benthic community and the time constant, T_p' for phytoplankton growth. The criteria are applied specifically to the conditions that exist in South San Francisco Bay.

MICROBIOLOGY

HETEROTROPHIC BACTERIA AND BACTERIVOROUS PROTOZOA IN OCEANIC MACROAGGREGATES

David A. Caron, Paul G. Davis, Laurence P. Madin and John McN. Sieburth

Oceanic macroaggregates (marine snow and Rhizosolenia mats) sampled from the Sargasso Sea are associated with bacterial and protozoan populations up to four orders of magnitude greater than those present in samples from the surrounding water. Filamentous, curved, and spiral bacteria constituted a higher proportion of the bacteria associated with the particles than were found among bacteria in the surrounding water. Protozoan populations were dominated numerically by heterotrophic microflagellates, but ciliates and amoebas were also observed. Macroaggregates are highly enriched heterotrophic microenvironments in the oceans and may be significant for the cycling of particulate organic matter in planktonic food chains.

BIOCHEMICAL COMPOSITION AND SHORT-TERM NUTRIENT INCORPORATION PATTERNS IN A UNICELLULAR MARINE CYANOBACTERIUM, Synechococcus (STRAIN DC-2)

Russell L. Cuhel and John B. Waterbury

The basic biochemical composition of a unicellular marine Synechococcus sp. (strain DC-2) is presented. The subcellular distributions of C, S, and P are given for uniformly-labeled and short-term incorporation measurements. Uptake of several organic compounds is documented.

CHEMOSYNTHETIC MICROBIAL MATS OF DEEP SEA HYDROTHERMAL VENTS

Holger W. Jannasch

Microbial mats at deep sea hydrothermal springs are of chemosynthetic origin and differ characteristically from phototrophically sustained mats by the composition of morphological types. Commonly observed were filaments of the genera Beggiatoa and Thiothrix as well as cyanobacterium-type trichomes which are, although hardly photosynthetic, morphologically indistinguishable from species of the genus Calothrix. Also abundant in the mats and readily isolated were organisms of the genera Thiobacillus, Thiomicrospira, Hyphomonas and Hyphomicrobium as well as a free-living, strictly anaerobic spirochaete. As indicated by their characteristic intracellular membrane systems, "Type I" methylotrophic bacteria amounted to 20 percent of the total cell count in those mat samples sectioned for transmission electron microscopy. Manganese-iron deposits enveloped large numbers of intact microbial cells, but no clue on the latter's contribution to the formation of these deposits was apparent. In contrast to photosynthetically grown stromatolites, no fossil chemosynthetic microbial mats have so far been reported.

MICROBIAL PROCESSES AT DEEP SEA HYDROTHERMAL VENTS

Holger W. Jannasch

The primary production of organic carbon by chemosynthetic sulfur-oxidizing bacteria has been proposed to provide the base of the food chain for the extensive populations of animals found at hydrothermal vents at depths of 2611 m. The oxidation of reduced inorganic compounds (such as H_2S, $S°$, $S_2I_3^-$, NH_4^+, NO_2^-, Fe^{2+} and possibly Mn^{2+}) as the source of energy for chemosynthesis is equivalent to the role of light in photosynthesis. Epifluorescence microscopy and biomass determinations demonstrated substantial bacterial densities in the emitted vent waters. Multi-layered mats of unicellular bacteria were observed, often encased in heavy Mn/Fe deposits, as well as assemblages of Leucothrix/Thiothrix-like filaments and others resembling trichomes of apochlorotic cyanobacteria. Masses of Beggiatoa filaments were found on artificial surfaces deposited near the vents for 11 months. To date, species of the genera Thiomicrospira, Thiobacillus and Hyphomonas have been isolated and studied in detail. Furthermore, a pure culture of an anaerobically chemosynthetic, extremely thermophilic, methanogenic bacterium was recently obtained as well as a number of "Type I" methylotrophic bacteria oxidizing methane and methylamine. The gills of bivalves, collected from areas intermittently flushed with H_2S-containing vent water and oxygenated ambient seawater, contained masses of bacteria showing high activities of sulfur metabolism and Calvin-Benson cycle enzymes. Likewise the "trophosome" tissue of the gutless tube worm Riftia was found to consist of procaryotic cells exhibiting ATP-generating and CO_2-reducing activity. Thus, three locations of chemosynthetic production are proposed: (1) within the subsurface vent system, (2) in microbial mats in the immediate surrounding of the vents, and (3) in various symbiotic associations with invertebrates. It appears that the predominant chemosynthetic production and most efficient transfer of organic carbon to the vent animals occurs via symbiosis.

DEEP SEA BACTERIA: ISOLATION IN THE ABSENCE OF DECOMPRESSION

Holger W. Jannasch, Carl O. Wirsen and
Craig D. Taylor

Sampling and pure culture isolation of deep sea bacteria without loss of in situ pressure is required in order to determine the viability of decompression-sensitive strains. This was achieved by using a pressure-retaining seawater sampling system in connection with a pre-pressurized hyperbaric isolation chamber. Rates of growth and substrate uptake of the majority of isolates show highly barotolerant characteristics while the remainder (4 out of 15) exhibited barophilic characteristics.

INEFFICIENT ACCUMULATION OF LOW LEVELS OF MONODISPERSED AND FECES-ASSOCIATED POLIOVIRUS BY OYSTERS

Edward F. Landry, James M. Vaughn, Thomas J. Vicale and Roger Mann

The accumulation of low levels (1.112 to 1.18 PFU/ml) of both feces-associated and monodispersed poliovirus by oysters (Crassostrea virginica or gigas) and clams (Mercenaria mercenaria) was investigated. These levels were chosen to duplicate the conditions present in light to moderately polluted waters. Experiments were performed in both small and large-scale, flowing seawater systems developed to mimic the natural marine habitats of shellfish. Under these conditions, viral accumulation by physiologically-active shellfish was only noted when water column concentrations exceeded approximately 1.11 PFU per ml. Bioaccumulation increased with increasing concentrations of both monodispersed and feces-associated viruses. At virus concentrations below this level, viruses were seldom detected in either clams or oysters. Evidence indicated that the lack of accumulation was not the result of inefficient extraction/detection methods. The modified Cat-Floc beef extract procedure used in the experiment was found to be capable of detecting as few as 1.5 to 2.1 PFU per shellfish. Evidence is presented to indicate that an uptake-depuration equilibrium was present at virus exposure levels of 1.11 PFU/ml, but not at 1.11 PFU/ml. The results suggested that viral accumulation by shellfish may not be efficient at water column concentrations below e1.11 PFU/ml.

NITROGEN FIXATION AND NITRATE UTILIZATION BY MARINE AND FRESHWATER Beggiatoa

Douglas C. Nelson, John B. Waterbury and Holger W. Jannasch

Four newly isolated marine strains of Beggiatoa and five freshwater strains were tested for nitrogen fixation in slush agar medium. All strains reduced acetylene when grown microaerobically in media containing a reduced sulfur source and lacking added combined nitrogen. The addition of 2 mmol N, as nitrate or ammonium salts, completely inhibited this reduction. Although not optimized for temperature or cell density, acetylene reduction rates ranged from 3.2 to 12 nmol $\cdot$ mg prot^{-1} min^{-1}. Two freshwater strains did not grow well or reduce acetylene in medium lacking combined nitrogen if sulfide was replaced by thiosulfate. Two other strains grew well in liquid media lacking both combined nitrogen and reduced sulfur compounds but only under lowered concentrations of air. This is the first report of nitrogen fixation by Beggiatoa. All freshwater strains grew well in medium containing nitrate as the combined nitrogen source. Since they did not reduce acetylene under these conditions, we infer that they can assimilate nitrate.

SAMPLER INCUBATION DEVICE, INSTRUMENTATION FOR THE IN SITU, TIME-COURSE MEASUREMENT OF MICROBIAL RATE PROCESSES

Craig D. Taylor, John J. Molongoski, Kenneth W. Doherty, Per O. Ljungdahl and Deborah H. Wiebe

A sampler incubation device (SID) is described that will perform in situ time-course incubation experiments at any depth within the marine water column. A one-liter sample is automatically taken at depth and simultaneously mixed with an appropriate radiotracer. During subsequent in situ incubation successive subsamples are withdrawn automatically from the main sample in a timed sequence and preserved for laboratory analysis. For incubations that are to be conducted at depths less than 10 m subsampling may also be effected manually via tubing leading from the instrument to the water surface. Representative data are shown illustrating the functioning of the SID in the anaerobic marine water column.

MICROBIAL ACTIVITIES IN THE EMITTED HYDROTHERMAL WATERS OF THE GALAPAGOS RIFT VENTS

Jon H. Tuttle, Carl O. Wirsen and
Holger W. Jannasch

In situ measurements of chemolithotro-
phic and some heterotrophic microbial
activities were made in the immediate
vicinity of actively discharging hydrother-
mal vents of the Galapagos Rift region at
depths of 2500 to 2600 m. The CO_2-assimila-
tion or chemosynthetic productivity in the
emitted vent waters, freshly mixed with
oxygenated ambient seawater of $2°C$, was
minor as compared to the bacterial biomass
produced within the subsurface vent system
prior to emission. Uptake of acetate and
glucose indicated the presence of mixotro-
phic or facultatively chemolithotrophic
bacteria in the emitted vent waters as
evidenced by isolations. Demonstration of
ribulose biphosphate carboxylase and
phosphoenol pyruvate carboxylase in cultures
of thiobacilli isolated from these vent
waters support the notion that chemolitho-
trophic sulfur-oxidizing bacteria are one
of the sources of primary production in the
form of particulate organic carbon for fil-
tering organisms at the deep sea hydrother-
mal environment. However, considering the
total amount of invertebrate biomass and the
rate of its growth and maintenance outside
of the turbid plume of emitted vent waters,
the larger portion of chemosynthetic sus-
tenance of the deep sea vent ecosystems
appears to be based on symbiotic associa-
tions between bacteria and invertebrates
rather than on the emission and consumption
of free-living bacteria.

In press: Marine Biology.

ISOLATION AND GROWTH OF CYANOBACTERIA FROM MARINE AND HYPERSALINE ENVIRONMENTS

John B. Waterbury and Roger Y. Stanier

In this chapter, the cyanobacteria of
marine and hypersaline environments will be
discussed separately; the physiological
properties which distinguish these cyanobac-
teria from others and the range of taxonomic
diversity encountered in saline environments
will be indicated.

M O D E L I N G

EVALUATING NEUTRAL MODELS: A REPLY TO COMMENTS BY UGLAND AND GRAY

Hal Caswell

Ugland and Gray have recently criticized
the neutral model analysis of species diver-
sity on several grounds, most notably that
one of the models used actually contains a
strong form of competition. I argue here
that the effect in question is more appro-
priately considered a form of random error
than of competition, since it does not have
a consistent sign. Moreover, the same
results can be derived from a neutral model
which does not include this effect. Thus
the conclusions of the neutral model study
cannot be an artifact of competition.

In press: Ecology.

COMPUTER MODELING OF ^{15}N UPTAKE AND REGENERATION EXPERIMENTS

Chris Garside and Patricia M. Glibert

A computer model simulating $^{15}NH_4^+$ or
$^{15}NO_3^-$ uptake experiments in which regenera-
tion of the same nutrient occurs is
described. The use of this model within a
reiterative program which fits values of
uptake and regeneration rates to experimen-
tal data is demonstrated and the results of
such computations are compared to other
methods of calculation of ammonium fluxes
commonly used in the literature. Some
advantages of the use of a computer model
approach over more standard calculation
approaches are presented; the greatest
advantage being a predictive capability
which permits testing of several experimen-
tal designs before executing the experi-
ments.

P H Y T O P L A N K T O N

LIMITATION OF MARINE PHYTOPLANKTON REPRODUCTION RATES BY ZINC AND MANGANESE

Larry E. Brand, William G. Sunda
and Robert R. L. Guillard

The reproduction rates of 21 species of marine phytoplankton were measured in media in which free zinc and manganese ion activities were controlled at different levels using EDTA-trace metal ion buffers. In general, the reproduction rates of neritic species were limited by zinc activities below $10^{-11.5}$M, while those of oceanic species were either not limited or only slightly limited at the lowest zinc activity attained in the experiment, ca. 10^{-13}M. Likewise, the reproduction rates of oceanic coccolithophores were either not limited or only slightly limited by the lowest manganese activity attained, ca. 10^{-11}M, but those of a neritic coccolithophore and all diatoms, both neritic and oceanic, were limited below a manganese activity of 10^{-10}M. The habitat related patterns in zinc and manganese requirements of different species are consistent with the oceanic-neritic distributions of these metals and, therefore, provide evidence that zinc and manganese have been important selective forces on marine phytoplankton populations and communities and thus are important ecological factors.

VERTICAL DISTRIBUTION AND ISOTOPIC FRACTIONATION OF LIVING PLANKTONIC FORAMINIFERA FROM THE PANAMA BASIN

Richard G. Fairbanks, Marc Sverdlove,
Rosemary Free, Peter H. Wiebe
and Allan W. H. Be

Oxygen isotope measurements of the shells of planktonic foraminifera living in the water column between 0 and 2000 meters in the Panama Basin indicate that planktonic forams proliferate exclusively in the euphotic zone. The dominant species, G. dutertrei, was caught in maximum abundance in the chlorophyll maximum zone. Other species collected were temperature stratified vertically according to the same temperature ranking derived from surface plankton tows over broad geographic regions. Vertical descent out of the euphotic zone is common for many species. A sizeable portion of the population of G. theyeri was found descending at a rate of 170 m/day; no calcite was added once the population left the euphotic zone. The carbon isotopic composition of the shells of G. dutertrei and G. theyeri are the same as the estimated carbon isotopic composition of ambient sea water HCO_3.

SEASONAL VARIATIONS IN THE UTILIZATION OF AMMONIUM AND NITRATE BY PHYTOPLANKTON IN VINEYARD SOUND, MASSACHUSETTS USA

Patricia M. Glibert, Joel C. Goldman
and Edward J. Carpenter

The nitrogenous nutrition of the phytoplankton in Vineyard Sound, Massachusetts, was investigated over a 15-month period. Highest rates of ammonium uptake were observed immediately prior to, or during, the diatom bloom periods, and with one exception were found in the <10 um size class. The saturating rate of ammonium uptake correlated well with temperature and gave Q_{10} values of 2.6-3.2; correlations with ambient solar irradiation were not nearly so clear. Uptake rates of nitrate relative to ammonium were low except during the winter bloom of the diatom Rhizoselenia delicatula; yet calculation of the f ratio revealed that nitrate was relatively important in the nitrogenous nutrition of the phytoplankton throughout the year.

OCEANIC NUTRIENT CYCLES

Joel C. Goldman

Our perception that the euphotic zone of nutrient-impoverished marine waters is a steady state system characterized by low phytoplankton biomass and growth rates is based, to a large extent, on the choice of

temporal and spatial scales upon which the important biological and chemical measurements typically are made. It is the local environment surrounding a phytoplankton cell, however, that controls the availability of nutrients required for growth. Whether the distribution of nutrients in such microenvironments is different from the nutrient concentrations we measure in large-volume samples is a question of some controversy.

One way that all microbes including phytoplankton may cope with nutrient impoverishment is to concentrate nutrients by attaching to available surfaces in the water column. Such surfaces may be small organic aggregates tens of microns in size. Colonization of these aggregates by a variety of microbes could lead to "oases in the desert" in which nutrients are stored and cycled in an efficient manner by the food chain interactions of small autotrophs, equally small microflagellate grazers, and bacteria. Each aggregate could then be thought of as a complete life-support system.

If such microenvironments are the major source of microbial activity in oligotrophic marine waters then it is possible to reconcile many of the current controversies regarding primary production, growth rates, and rapid nutrient uptake.

In press: "Flows of Energy and Materials in Marine Ecosystems: Theory and Practice," edited by M. Fasham, Plenum Press.

Supported by: NSF Grant OCE80-24445.

WHOI Contribution No. 5206.

CO$_2$ EXCHANGE BETWEEN AIR AND SEAWATER: NO EVIDENCE FOR RATE CATALYSIS

Joel C. Goldman and Mark R. Dennett

Enzymatic catalysis has been suggested to play a major role in regulating the mass transport of CO$_2$ from the atmosphere into the oceans. We could not find evidence for this possibility in a series of gas exchange experiments in which we compared the gas transfer rate coefficients for samples obtained from various natural seawaters, with and without the addition of carbonic anhydrase, with those from artificial seawater. Wind-induced turbulence appears to be the major factor controlling the ocean's response to increases in anthropogenic CO$_2$.

In press: Science.

Supported by: NOAA Sea Grant NA80AA-D-0077.

WHOI Contribution No. 5244.

EFFECT OF NITROGEN SOURCE ON SHORT-TERM LIGHT AND DARK CO$_2$ UPTAKE BY A MARINE DIATOM

Joel C. Goldman and Mark R. Dennett

Based on a series of short-term incubations involving the marine diatom Chaetoceros simplex, precultured in NH_4^+-, NO_3^-- and urea-limited continuous cultures at several dilution rates, we found that the short-term specific rate of $^{14}CO_2$ uptake was uneffected by nitrogen enrichment with any combination of growth and enrichment nitrogen source. Similar enrichments in the dark, however, led to significant CO$_2$ uptake under all conditions of NH_4^+ enrichment and to similarly enhanced CO$_2$ uptake, but only at high growth rates, when urea was the source of enrichment nitrogen. These results lead us to conclude that short-term suppression of light CO$_2$ uptake by phytoplankton exposed to pulses of nitrogen, as found by others, probably is restricted to severely nitrogen-deficient cells. Enhanced dark uptake, in contrast, appears to be characteristic of phytoplankton under all degrees of nitrogen limitation, and, as such, may be useful as an "all or nothing" index of the nitrogen status of natural waters. There is some indication that the index may be useful in determining both the form of and the degree of nitrogen limitation, as well.

Supported by: NSF Grant OCE80-24445.

WHOI Contribution No. 5304.

NITROGEN IN THE MARINE ENVIRONMENT
III.5 Kinetics of Inorganic Nitrogen Uptake by Phytoplankton

Joel C. Goldman and Patricia M. Glibert

The kinetics of inorganic nitrogen uptake and assimilation by marine phytoplankton are far more complicated than commonly envisioned. The major complication is that tremendous uncoupling between NH_4^+ uptake by phytoplankton and growth can exist on temporal scales of minutes and less. In fact, depending on their physiological state, phytoplankton take up NH_4^+ in a non-linear fashion with fastest rates (far in excess of that requested to balance growth) occurring during the shortest intervals over which measurements can be made. This means that the NH_4^+ uptake rate of a phytoplankton population is dependent on three variables: the ambient concentration of NH_4^+, the cell physiological state, and the time of exposure to the concentration of NH_4^+.
Normally, only the first of these variables is considered in developing kinetic models of NH_4^+ uptake and subsequent phytoplankton

growth. When considering the latter two variables, it becomes virtually impossible to model quantitatively such relationships. It is our opinion that, for this reason, the well-established concept of K_s (the half saturation coefficient that describes the affinity a phytoplankton population has for a particular nutrient) probably has little meaning. This is particularly true if phytoplankton growing in nutrient-poor waters rely primarily on their rapid nutrient capabilities when exposed to elevated, but undetectable nutrient concentrations present in microenvironments.

QUASI K-SELECTED SPECIES, EQUIVALENCE, AND THE OCEANIC COCCOLITHOPHORID PLANKTON

Edward M. Hulburt

Coccolithophore species, other than Emiliania huxleyi and Gephyrocapsa oceanica, make up a group of about 20 species in the western North Atlantic and the Mediterranean. Most of the species are the same in both places and provide the same ordered decrease of abundances in both places, suggesting an equilibrium condition. Thus we may say 'if, given any species, one species belongs to a diverse coccolithophore group, then it occurs under equilibrium conditions and occurs in the deep ocean': this implies 'if the given species does not occur under equilibrium conditions or does not occur in the deep ocean, then it does not belong to such a diverse group.' Along the coast of Colombia and Ecuador in the Pacific growth conditions result in very uneven plankton concentrations indicating lack of equilibrium and the diversity of coccolithophores is reduced, certifying 'if the given species does not occur under equilibrium conditions, then it does not belong to a diverse coccolithophore group.' In the Gulf of Persia the water is quite shallow, making possible stranding of coccolithophores on the bottom during the unstratified winter period, and just a very few coccolithophores species are present. So this certifies 'if the given species does not occur in the deep ocean, then it does not belong to a diverse coccolithophore group.'

THE CAPACITY FOR CHANGE AND THE UNPREDICTABILITY OF THE PHYTOPLANKTON OF THE EAST COAST OF THE UNITED STATES

Edward M. Hulburt

Differences in the change of numerical abundance from time to time through the year and place to place along the U.S. east coast show Skeletonema costatum to have a greater capacity for change than Thalassionema nitzschioides. These differences emerge from the unpredictable occurrence and absence of Skeletonema from time to time through the year and from year to year at Woods Hole and from place to place along the U.S. east coast. Skeletonema's greater capacity for change than Thalassionema's transmit an inherently variable capacity for change to the whole phytoplankton, and the unpredictability of these species transmits this characteristic to the whole phytoplankton too.

USE OF LOGICAL EQUIVALENCE IN ECOLOGICAL RELATIONS

Edward M. Hulburt

1. What is equivalence ? When two simple statements are both true or both false, they are equivalent. When two compound statements are equivalent they are true by truth value analysis.

2. Compound statements describing ecological observations show relationship when the statements are equivalent. Two examples are the following.

3. 'If x is adapted to nutrient conditions of the southern Sargasso Sea, then x is not inherently responsive'. Let 'x' be any species except C. huxleyi. The equivalent formula is 'if x is inherently responsive, then x is not adapted to nutrient conditions of the southern Sargasso Sea'. Let 'x' be C. huxleyi. This is the first example.

4. The second example is 'if x experimentally responds to year-round temperatures or x observationally responds to year-round temperatures, then x is adapted to year-round temperatures' equivalent to 'if x is not adapted to year-round temperatures, then x does not experimentally respond and does not observationally respond to year-round temperatures'. Experimental and observational confirmation for several species is presented.

DINOFLAGELLATE REPRODUCTION

Lois A. Pfiester and Donald M. Anderson

Dinoflagellates are important members of the plankton in both fresh and marine waters. Over 1500 living species have been described, spanning a wide spectrum of morphology and nutrition. This review discusses the reproductive strategies of this diverse class, with emphasis on the common patterns of vegetative and sexual reproduction and the environmental control of these processes.

INSTRUMENTATION FOR THE MEASUREMENT OF PHYTOPLANKTON PRODUCTION

Craig D. Taylor, John J. Molongoski and Steven E. Lohrenz

Automated instrumentation is described that performs time-course incubation experiments directly in situ where natural conditions of temperature, light, hydrostatic pressure, etc., can be maintained. The sampler incubation device (SID) obtains a 1-liter sample from the water column and simultaneously introduces an appropriate radiotracer. During subsequent in situ incubation, 50 ml subsamples are withdrawn from the main incubating sample at equally spaced time intervals and preserved for laboratory analysis. Representative time course experiments employing the SID revealed non-linear carbon uptake within 0.5-1.0 h, emphasizing that end point analyses of even short duration can lead to large errors in estimating phytoplankton production rates. Studies of the rapid fluctuation in phytoplankton activity resulting from large order, cloud-induced variations in light intensity, and the application of cellular fractionation methods for measuring the intracellular distribution of newly fixed carbon illustrated the utility of instrumental time course techniques for studying phytoplankton physiology and community metabolism in situ.

P O P U L A T I O N   D Y N A M I C S

THE IMPORTANCE OF LIFE CYCLE EVENTS IN THE POPULATION DYNAMICS OF Gonyaulax tamarensis

Donald M. Anderson, Sallie W. Chisholm and Carl J. Watras

Life cycle transformations allow populations of the toxic dinoflagellate Gonyaulax tamarensis to colonize the benthos and the plankton alternately and are important factors regulating the initiation and decline of blooms in restricted embayments. When the dynamics of these estuarine populations were monitored during "bloom" and "non-bloom" years, it was shown that: 1) both years, germination of benthic cysts inoculated the overlying waters during the vernal warming period, but a large residual population remained in the sediments throughout the blooms; 2) the resulting planktonic population began growth under suboptimal temperature conditions; 3) the populations developed from this inoculum through asexual reproduction until sexuality (and cyst formation) were induced; 4) encystment was not linked to any obvious environmental cue and occurred under apparently optimal conditions; and 5) an increase in the number of non-mitotic swimming cells (precursors to dormant cysts) accompanied the rapid decline of the planktonic population. Thus encystment, in combination with hypothesized losses due to advection and grazing, contributed substantially to the decline of the vegetative cell population.

We conclude that the encystment/excystment cycle temporally restricts the occurrence of the vegetative population and may not be optimized for rapid or sustained vegetative growth and bloom formation in shallow embayments. The factors that distinguish "bloom" from "non-bloom" years thus appear to be operating on the growth of the planktonic population.

PHENOTYPIC PLASTICITY IN LIFE HISTORY TRAITS: DEMOGRAPHIC EFFECTS AND EVOLUTIONARY CONSEQUENCES

Hal Caswell

Although much life history theory assumes otherwise, most life history traits

exhibit phenotypic plasticity in response to environmental factors during development. Plasticity has long been recognized as a potentially important factor in evolution, is known to be under genetic control, and may or may not be adaptive. The notion of adaptive plasticity contrasts with the idea that developmental homeostasis is a major evolutionary goal. The conflict was re-solved in principle by Ashby's cybernetic analysis of homeostasis, which showed how plasticity in "response variables" might act to screen "essential variables" from the impact of environmental disturbance. To apply this analysis to life history plasti-city, it must be incorporated into a demo-graphic model. An approach is presented here using life cycle graphs and matrix pro-jection models. Plasticity in response to temporal variation leads to time varying matrix models; plasticity in response to spatial variation leads to models structured by criteria other than age. The adaptive value of such plasticity can be assessed by calculating its effects on a suitable measure of fitness: long-term growth rate for time-invariant models, expected growth rate discounted by variance for time-varying models. Three examples are analyzed here: plasticity in the rate of development from one instar to the next in a stage-classified model, plasticity in multiplicative yield components, and plasticity in dormancy as a response to environmental cues. Development rate plasticity is adaptive if reproductive value increases from the instar in question to the next, maladaptive otherwise. Plasticity in yield components reduces fit-ness variance and hence is adaptive if the responses of successive developmental steps (e.g., flowers/stem, seeds/flower) are negatively correlated. Plasticity in dormancy is adaptive if it responds to the same factor(s) influencing mortality, but with opposite sign. A number of important problems, including tradeoffs between gene-tic and phenotypic adaptation and the dis-tinction between continuous and discontinu-ous plasticity remain to be solved.

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ESTIMATING POPULATION SIZE FROM RELATIVE ABUNDANCE DATA MEASURED WITH ERROR

Jeremy S. Collie and Michael P. Sissenwine

A modified DeLury method to estimate fish population size from relative abundance data is developed. In addition to estimat-ing catchability coefficients, the technique accounts for error in the measurement of relative abundance. A general-purpose non-linear regression subroutine is used to fit the model. The technique is demonstrated using Northeast Fisheries Center bottom trawl survey data as a measure of relative abundance. Fitting was carried out for four fish populations: Georges Bank and Southern New England yellowtail flounder (Limand ferruginea), Georges Bank and NAFO S.A. 4X haddock (Melanogrammus aeglefinus). Catch-ability coefficients calculated in this manner are consistent with prior estimates. In addition, the technique smooths the survey data by filtering measurement error from true fluctuations in population size. Population size estimates for haddock derived by this method agree closely with virtual population analysis (VPA) estimates.

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S A L T   M A R S H E S

THE FATE OF METALS INTRODUCED INTO A NEW ENGLAND SALT MARSH

Anne E. Giblin, Ivan Valiela and John M. Teal

As part of a study to investigate the effect of chronic eutrophication on salt marshes, a sewage sludge fertilizer has been applied to experimental plots in Great Sippewissett Marsh, MA, since 1974. The fertilizer contains substantial amounts of heavy metals. Sediments from fertilized plots contain elevated levels of Cu, Cd, Zn, Fe, Mn, Cr, and Pb. The above and below ground portions of the dominate grass, Spartina alterniflora, contain significantly higher levels of Cd, Cr, Cu, and Zn when compared to control plots. The mussel, Modiolus demissus, from fertilized plots contains elevated levels of Cu, Cd, and Cr. The fiddler crab, Uca pugnax contains more Cu and Cd than control animals. Low marsh sediments fertilized for eight years re-tained 15 percent Cd, 24 percent Fe, 27 per-cent Mn, 28 percent Zn, 45 percent Cr, 49 percent Cu, and 60 percent of the Pb in the fertilizer. Plots which had only received fertilizer for one year retained a higher percentage of the metals which had been added. The differential solubilization of metals from the fertilizer appear to be one factor influencing metal retention on the plots although changes in sediment chemistry due to nutrient addition are also a factor.

In press: Water, Air and Soil Pollution, Vol. 19.

EFFECTS OF WRACK ACCUMULATION ON
SALT MARSH VEGETATION

Jean Hartman, Hal Caswell and
Ivan Valiela

A major source of disturbance in New
England salt marshes is the local accumula-
tion of wrack, composed primarily of
Spartina alterniflora and Zostera marina.
Mats of wrack accumulate throughout the
marsh, killing or damaging the plants
beneath them. This study examines the
formation of disturbance patches, their
distribution in the vegetation and their
subsequent successional development. Exper-
imental placement of mats of wrack reveals
that the zones of the marsh differ little in
their sensitivity to this form of distur-
bance. However, the dominant grass species
differ in their response to disturbance.
The overall vegetation of the marsh reflects
the pattern of disturbance in space and time
as well as the successional development
which occurs within individual patches.

THE FATE OF POLLUTANTS IN
AMERICAN SALT MARSHES

John Teal, Anne Giblin
and Ivan Valiela

Studies of pollutants in coastal wet-
lands have been made all along the coasts
of the United States. In some studies,
pollutants carried by rivers or coastal
water have been investigated, in others
experimentally added pollutants have been
investigated. We have been experimentally
applying sewage sludge to a New England
salt marsh for 10 years. Sludge contains
plant nutrients and a wide range of
heavy metals, halogenated hydrocarbons (in-
cluding PCB's and pesticides), and hydrocar-
bons (including polynuclear aromatic hydro-
carbons).

Heavy metal pollutants tend to be bound
to sediments and remain close to the source
of contamination. Most iron, mercury and
lead is retained by sediments in Georgia and
New England salt marshes. Metals such as
cadmium, zinc and chromium which form
soluble complexes in sea water pass through
coastal wetlands relatively rapidly. Marsh
grasses in Georgia and Massachusetts and sea
grasses in Texas have been shown to absorb
metals and nutrients from sediments in which
they are growing. (In Louisiana, river-
borne sediments supply sufficient nutrients
to fully support the marsh production).
Incorporation into above-ground plant parts
can be an important avenue for remobiliza-
tion of some metals.

In a New England experiment in which
pollutant additions ceased after seven
years, cadmium decreased to background
levels in surface sediment in about two
years, although lead levels did not change
measurably. Lead concentrations in
organisms living in polluted plots were
never different from those in controls.
Cadmium concentrations in animals were
significantly higher in polluted areas, but
decreased within two years to background
levels depending upon feeding type. Two
years after additions ceased, mercury had
decreased by 50 percent in marsh areas
flooded twice a day, but did not change
measurably in marsh areas higher in eleva-
tion. At no time did mercury levels in
marsh organisms in any one site reflect the
changing levels in the sediments on which
they were living, although there was an
inverse correlation between mercury in
organisms and sediment organic content at
different sites. Metal retention and
mobilization is related to sulfide concen-
tration and the very labile sediment redox
values.

There have been two instances of
deleterious effects of organic compounds in
ten years of sludge additions. Fiddler
crabs suffered a 50 percent reduction of
population size due to the presence of
Aldrin in the sludge. The effect was con-
fined to the immediate area of the applica-
tion, not spread by tidal flows two years
after Aldrin was absent in the sludge.
Tabanid larvae were reduced in density asso-
ciated with a body burden of PCB's and other
halogenated hydrocarbons.

The primary effect of addition of sewage
seems, in general, to be an increase in
productivity of marsh higher plants as a
result of the increased nitrogen. The
associated increase in protein in the
plants results in an increase in
herbivorous animals, primarily insects, and
in detritivores.

THE REGULATION OF PRIMARY PRODUCTION AND DECOMPOSITION IN A SALT MARSH ECOSYSTEM

Ivan Valiela, Brian Howes,
Robert Howarth, Anne Giblin,
Ken Foreman, John M. Teal
and John E. Hobbie

Production by higher plants in salt marshes is limited by available nitrogen and the availability of nitrogen for plant uptake is largely determined by the redox condition of the sediments. Salinity or water stress may affect plant growth in certain areas with extreme conditions.

Decay of plant matter takes place primarily by leaching of soluble compounds and actual degradation by decomposers and both processes are affected by nutrient availability. Below-ground production of organic matter is higher than above ground and is consumed in situ primarily by sulfate-reducing microorganisms. Methane producers and denitrifiers have smaller roles.

Eutrophication of salt marshes would increase above-ground relatively more than below ground biomass and would also increase decay rates of organic matter above and below ground.

SOME LONG-TERM CONSEQUENCES OF SEWAGE CONTAMINATION IN SALT MARSH ECOSYSTEMS

Ivan Valiela, John M. Teal,
Charlotte Cogswell, Sarah Allen,
Dale Goehringer, Richard Van Etten
and Jean Hartman

We have treated experimental salt marsh areas for 12 years with sewage sludge-based fertilizer. Production of grasses increased, mainly in response to nitrogen, with a lag-time that was shorter the higher the dosage. After about four years there was a slight decrease in maximum standing crop in fertilized plots which, however, remained significantly above the fairly constant level in the controls. The Spartina alterniflora changed from dense, narrow-leaved and stemmed plants to taller, thicker and more widely spaced plants. There was about 1 percent increase in N concentration in the fertilized plants which stimulates a considerably higher change in the level of herbivory by insects, mammals and birds. The number of higher plant species decreased from 11 in control plots to 4 at the highest sludge dosage. Changes in the plant mosaic on the marsh are exaggerated by fertilization but take years to occur. We have found no detrimental effects to the plants from eutrophication or the contaminants in the sludge.

TAXONOMY

Pinna deltodes MENKE NEWLY DESCRIBED AND DIFFERENTIATED FROM P. bicolor GMELIN (BIVALVIA, PTERIOIDA)

Amelie Scheltema

Pinna deltodes Menke is a valid Indo-Pacific species of Pinnidae morphologically similar to P. bicolor Gmelin. It can be distinguished from P. bicolor in Australia by the presence of regular, sharply defined, pinkish-buff lateral bands of subepithelial gland cells along the inner fold of the posterior mantle margin and by the position of the posterior adductor muscle scar at the posterior edge of the dorsal nacreous layer. The subepithelial gland cells are coarsely granular; they are not acid or neutral mucopolysaccharides (mucins) or muco- or glycoproteins (mucoids). The preferred habitat of P. deltodes is a hard substrate, either within cobble flats or beneath boulders, coral blocks, and bombies. The species extends from off eastern Africa to eastern Australia and as far north as Pakistan and probably the Red Sea, from the intertidal zone to 140 m.

ZOOPLANKTON

TIDALLY GENERATED HIGH-FREQUENCY INTERNAL WAVE PACKETS AND THEIR EFFECTS ON PLANKTON IN MASSACHUSETTS BAY

Loren R. Haury, Peter H. Wiebe, Marshall H. Orr and Melbourne Briscoe

Tidally generated internal wave packets occur twice a day during late summer in Massachusetts Bay, U.S.A. The packets are formed at Stellwagen Bank and propagate into the Bay at about 60 cm sec^{-1}; they dissipate in shallow water at the western side of the Bay. The dominant waves in packets have lengths of about 300 m, periods of between 8 and 10 min, and amplitudes of up to 30 m. Overturning of the waves has been observed acoustically over Stellwagen Bank, in the deep (80 m) waters in the center of the Bay, and during dissipation in shallow water. The effects of the internal waves on the distribution of plankton were investigated in August 1977 using an instrument package (Longhurst-Hardy Plankton Recorder, in situ fluorometer, CTD) towed either at a constant depth or following an isotherm through wave packets. Phytoplankton and zooplankton are carried passively up and down by the internal waves; no evidence was found for an active response by zooplankton to vertical displacements by the waves. Vertical distributions of the plankton were altered by overturning of waves and subsequent mixing. Patterns of horizontal distributions of plankton determined by constant-depth tows were dominated by the effects of internal wave vertical displacements. Isotherm-following tows removed much of the variability due to wave displacement, but problems of following rapidly moving isotherms introduced considerable smaller-scale variability. Changes in zooplankton abundance on tow length scales (600-1200 m) were not correlated with temperature, salinity, or density; some significant correlations with chlorophyll fluorescence occurred. Twice a day for several hours or more, phytoplankton were vertically displaced by as much as 30 m, with a period of about 10 min. The light level plant cells experienced varied from 0.1 to 26 percent of the ambient surface illumination. This rapid change in light should alter fluorescence yields of plant cells and affect continuous in situ measurements of chlorophyll fluorescence. The timing of internal wave packets varies with the semidiurnal tidal cycle and therefore interacts with the day-night cycle to significantly alter the light regime experienced by plant cells over a two-week period. This could affect the primary productivity of the Bay in the area affected by internal wave packets. The sporadic, apparently rare, occurrence of internal wave overturning and mixing events in the deep waters of the Bay could enhance primary production by increasing nutrient input to the mixed layer. This effect should be greatly enhanced in the shallow waters where the internal waves dissipate. Comparison of acoustic and plankton recorder data showed that much of the intense acoustic backscattering seen in high-amplitude (10-20 m) internal waves is due to physical structure and processes, and not to the presence of zooplankton.

In Situ GRAZING RATES FOR THREE SPECIES OF SALPS

Larry P. Madin and Catherine M. Cetta

The fluorometric measurement of chlorophyll and its degradation products in the guts of salps has been used as a means of calculating in situ grazing rates. Salps are particularly suitable for this method because they are non-selective filter-feeders large enough to be individually collected by divers. Filtering rates calculated in this way increase exponentially with body length. For Pegea confoederata and Salpa maxima, gut-pigment rates compare closely with rates measured in laboratory particle-clearance experiments. Salpa cylindrica has proved impossible to maintain in the laboratory and the gut-pigment results are the first feeding data for this species. Intercomparison experiments which measured filtering rates of the same salps simultaneously showed no significant difference between methods. Filtering rates for all species examined are high, on the order of liters per hour. Weight-specific filtering rates appear to increase as salps become larger, in contrast to many other herbivores. The gut-pigment method permits measurements of filtration and ingestion by herbivores on an almost instantaneous basis and could be a valuable tool for assessing grazing impact in field situations.

THE SWIMMING BEHAVIOR OF THE LARVAE OF
THE OCEAN QUAHOG, Arctica islandica

Roger Mann and Charlotte C. Wolf

Trochophore larvae of the Ocean Quahog, Arctica islandica, swim continuously. At a constant temperature of 12°C they are negatively geotactic, have no phototactic response and exhibit no change in swimming behavior in the pressure range 1-3 bars. In a vertical thermal gradient from 9 to 25°C the geotactic response is reduced; the trochophores swim throughout the experimental chamber and show no temperature preference.

Veliger larvae of A. islandica alternate between periods of active upward swimming in vertically oriented helices and periods of passive sinking with the velum either trailing or retracted between closed valves. They do not have the ability to swim in the horizontal plane and, in the length range 161 μM-212 μM, show no geotactic or phototactic response. When exposed to sequential increases and decreases in hydrostatic pressure at 12°C larvae in the length range 161 μM-196 μM consistently exhibited a net upward movement following an increase in pressure and a net downward movement following a decrease in pressure. The threshold pressure change to elicit response is 1.5 bars. Larvae of 171 μM length respond to increased pressure by both decreasing the diameter of the helix and increasing the height gain per rotation. Larvae of 196 μM length respond to increased pressure by increasing height per rotation and vertical velocity. Larvae of 212 μM length exhibit no significant change in swimming behavior with increased pressure. In a vertical thermal gradient early veliger's swim in the range 7-23°C with preferential aggregation, depending upon size, in the range 12-18°C. Larvae of 214 μM length show no temperature preference in the range 6-21°C.

The implication of the observed behavior on seasonal depth distribution of A. islandica larvae in the Middle Atlantic Bight is discussed.

DIGESTION RATES AND ASSIMILATION
EFFICIENCIES OF SIPHONOPHORES FED
ZOOPLANKTON PREY

Jennifer E. Purcell

Digestion times and assimilation efficiencies are critical factors used in calculations of carbon and nitrogen budgets. Digestion times of natural copepod prey differed significantly among 4 genera of siphonophores (p $\ll$0.001), from a minimum of 1.6 h to a maximum of 9.6 h. Assimilation efficiencies, in contrast, were uniformly high; 87 to 94 percent for carbon and 90 to 95 percent for nitrogen. Nitrogen assimilation consistently was greater than carbon assimilation. Assimilation efficiencies calculated according to dry weight substantially underestimated assimilation of carbon and nitrogen, while calculations using ash-free dry weights and ash-free to dry weight ratios approached values for carbon assimilation. These values are appreciably higher than most of the assimilation efficiencies previously measured for a few other planktonic carnivores. These results indicate very efficient digestion of food by siphonophores in oceanic environments where prey capture may be infrequent.

PREDATION OF Acartia tonsa ON A
DINOFLAGELLATE AND A TINTINNID

Nancy K. Sanders and
Diane K. Stoecker

The calanoid copepod, Acartia tonsa, preys on both the dinoflagellate, Heterocapsa triquetra, and the tintinnid ciliate, Favella sp., in laboratory experiments. The ingestion rate of A. tonsa increases linearly with increasing dinoflagellate density until a maximum ingestion rate is obtained at densities of about 1000 cells ml^{-1}. Above this prey density, which is commonly exceeded during dinoflagellate blooms, the ingestion rate of H. triquetra appears to decline. With Favella as the sole prey, ingestion rate also increases with cell density up to and possibly above prey densities of 3.4 cells ml^{-1}. Favella density in situ rarely exceeds 3 cells ml^{-1}. The clearance rate of A. tonsa for Favella, which is about 4.4 ml copepod^{-1} h^{-1}, is higher than the average clearance rate for H. triquetra.

Predation by A. tonsa on Favella is not effected by the presence of H. triquetra, even when this dinoflagellate is more abundant in terms of C and N than Favella. We hypothesize that under certain circumstances copepod predation may be important in limiting ciliate populations.

LONG-DISTANCE DISPERSAL OF PLANKTONIC LARVAE AND THE BIOGEOGRAPHY AND EVOLUTION OF SOME POLYNESIAN AND WESTERN PACIFIC MOLLUSKS

Rudolf S. Scheltema and
Isabelle P. Williams

The wide geographic range of many contemporary marine molluscan species throughout Polynesian and western Pacific Islands is accounted for by long distance dispersal of larvae. Plankton taken in the tropical and temperate central Pacific Ocean between Hawaii and New Zealand and from 160°W to 180°W longitude contained teleplanic veligers including, but not restricted to, the gastropod families Neritidae, Architectonicidae, Triphoridae, Ovulidae, Cypraeidae, Naticidae, Cymatiidae, Bursidae, Tonnidae, Muricidae, Thaididae, Coralliophilidae, Columbellidae, Turridae and Conidae; the bivalve families Pinnidae and Teredinidae; and a number of other as yet undetermined taxa. The present study considers some members of three gastropod families with teleplanic larvae (viz. Architectonicidae, Naticidae, and Coralliophilidae) and also some representatives of the bivalve family Pinnidae.

Fossil evidence from western Pacific Islands shows that molluscs with a long planktonic life have occurred throughout the Tertiary and that contemporary families that have a teleplanic larva are largely the same as those found in the fossil record. It is assumed that teleplanic larvae in the geologic past were carried by surface currents as they are today and that the general direction of larval dispersal can be inferred from the paleocirculation.

Fossil species having a long planktonic larval life of many months usually are shown to have had a greater geographic range than species with a shorter duration in the plankton. Concomitantly, fossil species with teleplanic larvae also persist over several geologic epochs whereas those with non-planktonic development appear to be more restricted in temporal distribution. A different biogeographic and evolutionary

outcome may be expected in species with a planktonic life of only a few weeks.

More evidence on the life history of both fossil and contemporary species is required to provide further insights into the evolutionary significance of planktonic and non-planktonic development and larval dispersal in marine mollusks.

In press: Bulletin of Marine Science.

GROWTH OF Favella SP. (CILIATA, SUBORDER TINTINNINA) AND OTHER MICROZOOPLANKTERS IN CAGES INCUBATED IN SITU AND COMPARISON TO GROWTH IN VITRO

Diane K. Stoecker, Linda H. Davis
and Andrea Provan

Microplankton cages with porous polycarbonate membrane sides were used to investigate the population growth of Favella sp., a large tintinnid which preys on dinoflagellates, Balanion sp., a non-loricate ciliate which also preys on dinoflagellates, and two other tintinnids, Eutintinnus pectinis and Tintinnopsis kofoidi, at close to in situ conditions in a small estuary during a spring dinoflagellate bloom. The effects of temperature and food concentration on the growth of Favella and Balanion were also investigated in culture. Growth rates in the field were variable from day to day. The highest net growth constant (base e) observed for Favella in the cages was 0.032 (which is equivalent to a generation time of about 22 h) which is lower than growth constants which can be achieved in culture. We believe that food availability, parasitism by the dinoflagellate Duboscquella, and perhaps life cycle events all contributed to the lower net growth rate of Favella in the field. The highest net growth constant observed in the cages for Balanion was around 0.068 (which is equivalent to a generation time of 10.7 h) which is also lower than growth constants which can be achieved in culture. We believe the growth of Balanion populations in the cages was limited by both availability of small-sized dinoflagellates and by predation. The highest net growth constants observed for E. pectinis and T. kofoidi were 0.030 and 0.068, respectively; we know little about the factors controlling the growth of these tintinnids.

EFFECTS OF PROTOZOAN HERBIVORY AND CARNIVORY IN A MICROPLANKTON FOOD WEB

Diane K. Stoecker and Geoffrey T. Evans

The tintinnid, Favella, and the naked ciliate, Balanion, both eat the dinoflagellate, Heterocapsa triquetra; Favella also eats Balanion. This "trophic triangle" was investigated experimentally in the field and laboratory. Theoretical models were constructed to address the possible long-term consequences of this trophic ambiguity, in which one species is both a competitor of, and a predator on, another species.

Favella has higher per individual clearance and ingestion rates for Heterocapsa than Balanion. However, because Balanion grows faster than Favella, it may, under certain circumstances, have a greater negative impact on Heterocapsa blooms. In our experiments, Heterocapsa concentrations were, at least transiently, higher in the presence of both ciliates than in the presence of Balanion alone; we assume this was because Favella reduces the concentration of Balanion although it also eats Heterocapsa. This suggests that predation among planktonic ciliates can regulate the grazing pressure exerted by this assemblage on phytoplankton.

We constructed a Lotka-Volterra type model of this system and examined steady-state solutions. The relative gross production efficiencies in this model have an important influence on ecosystem structure. We found examples in which increasing the rate of predation on a species could increase its stable, steady-state concentration.

Our experimental results are consistent with the alternative in our model in which it is less efficient for Favella to eat Heterocapsa in the form of Balanion than directly and where increasing the grazing pressure of Favella would increase Heterocapsa concentrations, or slow their decline due to ciliate grazing. We hypothesize that omnivory by Favella may lengthen dinoflagellate blooms when both ciliates are present.

This type of trophic structure may be common among the microplankton because many heterotrophic microplankters are about the same size as their prey and thus competitors may often also be predators and prey. These complex interactions where trophic position is ambiguous are probably important in regulating grazing pressure by microzooplankters on phytoplankton and microzooplankton secondary production.

ZOOPLANKTON GRAZING DURING DINOFLAGELLATE BLOOMS IN A CAPE COD EMBAYMENT, WITH OBSERVATIONS OF PREDATION UPON TINTINNIDS BY COPEPODS

Jefferson T. Turner and Donald M. Anderson

The patterns and rates of feeding by the copepod Acartia hudsonica and larvae of the polychaete Polydora sp. were investigated during the spring in an estuarine embayment. These dominant macrozooplankters fed upon the natural particulate assemblages (predominantly dinoflagellates) spiked with the toxic dinoflagellate Gonyaulax tamarensis. G. tamarensis was ingested by both zooplankters, as was Heterocapsa triquetra, the most abundant alternative food item. Ingestion rates generally increased as dinoflagellate concentrations increased, resulting in a relatively constant (and low) filtration rate for each grazer. Dinophysis acuminata, another dominant dinoflagellate, was essentially ungrazed. Thus, the zooplankters rejected one dinoflagellate completely and consumed others in proportion to their availability but at low rates. Based on these low rates and the small number of A. hudsonica observed during the spring, we infer minimal grazing impact on a 1980 G. tamarensis bloom. In contrast, the impact of polychaete larvae may have been substantial, since their extreme numerical abundance more than compensated for low filtration rates.

In one instance, the tintinnid Eutintinnus pectinus was accidentally included in a grazing experiment. Our ingestion data demonstrate that A. hudsonica, when presented with a choice of tintinnids and several species of phytoplankton (G. tamarensis and D. accuminata) preferentially ingested the tintinnids. Since the nanoflagellate Chroomonas amphioxea was found within the loricae of many of the surviving tintinnids, this also provided a qualitative demonstration of the often-hypothesized nannoplankton to tintinnid to copepod link in a marine food chain.

EUPHAUSIID INVASION/DISPERSAL IN GULF STREAM COLD-CORE RINGS

Peter H. Wiebe and Glenn R. Flierl

Invasion/dispersal patterns in the distribution and abundance of euphausiid species in four young- to middle-aged Gulf Stream cold-core rings suggest that several

different physical exchange mechanisms are
operating. The most important of these
appear to be horizontal mixing in the mixed
layer and exchange due to movement into or
out of the trapped region at depth. A zone
of minimum exchange is evident between 150
and 400 meters.

In addition to physical transport into
or out of a ring, the distribution of a
species is a result of its behavioral and
physiological response to the new environ-
ment, and the biological effects of preda-
tion and competition with other species.
These aspects of euphausiid biology are less
well understood, but changes in vertical
distribution and abundance of warm water
species invading the ring environs suggest
that only a few species such as Stylocheiron
carinatum are able to penetrate and take
advantage of the changing ring conditions in
young- to middle-aged rings (2 to 8 months).
Other near surface warm water species pene-
trate at slower rates regardless of whether
they are vertical migrators (Euphausia
brevis, E. hemigibba, E. tenera, Thysanopoda
aequalis) or non-migrators (S. suhmii, S.
abbreviatum). Deeper living species such as
S. affine, S. elongatum, Nematoscelis
microps, and N. tenella show minimal pene-
tration of ring core waters in these four
rings.

Cold-water species expatriated in cold-
core rings also show a varied response to
ring decay with some species disappearing
rapidly -- 3 to 4 months (Thysanoessa
longicaudata) -- and others persisting for
substantial periods -- 1/2 to 1 year (N.
megalops, E. krohnii). Distribution of the
latter two species indicate dispersal out
beyond the ring core at the surface in the
case of E. krohnii and at depths of 400 to
1000 meters in the case of N. megalops.

DEPARTMENT OF CHEMISTRY

Robert B. Gagosian, Department Chairman

CHEMISTRY

ORGANIC AND
BIOLOGICAL CHEMISTRY

BIOLOGICAL CONTROL OF THE REMOVAL OF ABIOGENIC PARTICLES FROM THE SURFACE OCEAN

W. G. Deuser, P. G. Brewer, T. D. Jickells and R. F. Commeau

Concurrent measurements of particle concentrations in the near-surface water and of particle fluxes in the deep water of the Sargasso Sea show a close coupling between the two for biogenic components. The concentrations of suspended matter appear to follow an annual cycle similar to that of primary production and deep-water particle flux. Although the concentration of particulate aluminum in the surface water appears to vary randomly with respect to that cycle, the removal of aluminum to deep water is intimately linked to the rapid downward transport of organic matter.

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THE INPUT OF ATMOSPHERIC $n-C_{10}$ TO $n-C_{30}$ ALKANES TO THE OCEAN

Robert A. Duce and Robert B. Gagosian

There are few data on organic compounds in the marine atmosphere. The only class for which any significant data base exists is the n-alkanes. Using available data on $n-C_{10}$ to $n-C_{30}$ alkanes in aerosols, rain, and in the gas phase from Atlantic, Pacific, and Indian Ocean regions, crude estimates of the deposition of n-alkanes to the world ocean are made. Deposition of gaseous and particulate n-alkanes by rain scavenging, of particulate n-alkanes by dry deposition, and of gaseous n-alkanes by direct vapor exchange with the ocean are evaluated. Rain scavenging of particulate n-alkanes appears to be the primary transport path to the ocean from the atmosphere. The total input of n-alkanes to the ocean from the atmosphere is estimated to be from 0.04 to 0.4 Tg/yr. The accuracy of these estimates could be evaluated by the analysis of carefully collected rain samples over several oceanic regions. More precise estimates of the atmospheric input of organic material to the ocean will have to await more information on the inputs of the various organic compound classes to the sea surface and further understanding of the reaction prod-

ucts, pathways and rates of transformation of these compounds in the atmosphere.

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WHOI Contribution No. 5058.

U. S. "MUSSEL WATCH" 1976-1978: AN OVERVIEW OF THE TRACE METAL, DDE, PCB, HYDROCARBON AND ARTIFICIAL RADIONUCLIDE DATA

J. W. Farrington, E. D. Goldberg, R. W. Risebrough, J. H. Martin and V. T. Bowen

Data are presented for trace metals, polychlorinated biphenyls (PCBs), aromatic hydrocarbons and $^{239,240}Pu$ in Mytilus edulis, M. californianus, and Crassostrea sp. collected in the U. S. Mussel Watch program in 1976, 1977 and 1978 from 62 locations on the U. S. east and west coasts. General similarities in geographical distributions of concentrations were present in all three years with at least an order of magnitude elevation of concentrations of Pb, PCBs, and fossil fuel hydrocarbons in bivalves sampled near the larger urban areas when compared to concentrations of these chemicals in bivalves sampled near less urbanized areas. There were no significant linear correlations among Pb, PCB, or hydrocarbon concentrations probably because of different modes of release of these chemicals to the environment and different biogeochemistries. Elevated Cd and $^{239,240}Pu$ concentrations in bivalves from the central California coast are apparently related to enrichments of Cd and nuclear weapons testing fallout $^{239,240}Pu$ in intermediate depth water of the North Pacific and upwelling of this water associated with the California Current system. Our data have revealed no evidence of local or regional systematic elevations of environmental concentrations of $^{239,240}Pu$ as a result of effluent releases from nuclear power reactors.

In press: Environmental Science and Technology.

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WHOI Contribution No. 5211.

HYDROCARBONS, POLYCHLORINATED BIPHENYLS, AND DDE IN MUSSELS AND OYSTERS FROM THE U.S. COAST, 1976-1978 - THE MUSSEL WATCH

John W. Farrington, Robert W. Risebrough,
Patrick L. Parker, Alan C. Davis,
Brock de Lappe, J. Kenneth Winters,
Dan Boatwright and Nelson M. Frew

Mytilus edulis, Mytilus californianus, Crassostrea virginica and Ostrea equestris were sampled at 90 to 100 stations around the United States coastline during each of three years - 1976, 1977, 1978. Data for concentrations of PCB, DDE, total hydrocarbons, gas chromatographically unresolved complex mixture hydrocarbons, and selected aromatic hydrocarbons are presented for most of the samples. Similar data for monthly samples of Mytilus edulis from Narragansett Bay, Rhode Island, and Mytilus californianus from Bodega Head, California, and laboratory intercalibrations are presented and discussed.

Monthly temporal changes of factors of two to ten were found for organic pollutants in mussels from the Narragansett Bay station. Concentrations of PCBs and fossil fuel hydrocarbons for some urban stations were one to two orders of magnitude higher than those in remote areas. The northeast "megapolis" of the U.S. coast from the Chesapeake Bay area to Boston, Massachusetts, clearly shows elevated concentrations of PCBs and fossil fuel hydrocarbons. The composition of aromatic hydrocarbons in samples with elevated concentrations shows both the influence of oil spill or chronic oil inputs and pyrogenic sources.

WHOI Technical Report 82-42.

BIOGEOCHEMISTRY OF AROMATIC HYDROCARBONS IN THE BENTHOS OF MICROCOSMS

J. W. Farrington, B. W. Tripp, J. M. Teal,
G. Mille, K. Tjessem, A. C. Davis,
J. B. Livramento, N. A. Hayward and
N. M. Frew

Investigations into the fate of petroleum compounds in the marine environment were carried out using experimental microcosms of two sizes and designs. Aromatic hydrocarbons or No. 2 fuel oil were spiked to the water of a 13 M^3 continuous flow system and to a 228 L. recycled flow system. The transport and alteration of this oil was traced in the sediment and benthic organisms (Glycera americana, Crepidula sp., and Nephtys incisa) of these microcosms. Measurable contamination was found in both sample types. The aromatic hydro-

carbon distribution, including relative isomeric distribution (e.g., C_2-phenanthrenes) was found to be different in sediment and in organisms from that which was originally introduced to the experimental microcosm. Differences in isomer distribution between Glycera and Crepidula were also detected. Based on the experimental data: molecular weight and specific isomeric form, biochemical processes, solubility, and particle adsorption/desorption influence the fate of petroleum compounds in benthic ecosystems.

WHOI Contribution No. 5094.

REVIEW OF MARINE ORGANIC GEOCHEMISTRY

Robert B. Gagosian

Over the past four years the field of marine organic chemistry has expanded in many directions. In order to cover the major areas of this expansion in a review of the type presented here, several major topic areas have been selected focusing on the processes responsible for the transport and transformation of organic material. Some of these topics have been discussed previously in a review of future research problems in marine organic chemistry. They include the organic geochemistry of 1. the atmosphere over the oceans and the air/sea interface, 2. dissolved material in seawater, 3. the composition and vertical flux of particulate material as it is transported through the water column, 4. recent marine sediments, 5. manuscripts focusing on transformation reactions, 6. metal-organic interactions including adsorption/desorption processes in the ocean, and 7. selected subjects in new areas of research.

WHOI Contribution No. 5315.

VERTICAL TRANSPORT AND TRANSFORMATION OF BIOGENIC ORGANIC COMPOUNDS FROM A SEDIMENT TRAP EXPERIMENT OFF THE COAST OF PERU

Robert B. Gagosian, Gale E. Nigrelli and John K. Volkman

Sediment trap experiments using the lipid biomarker approach were undertaken in the Peru coastal upwelling region to answer three main questions concerning the sources, transport and transformation of organic matter in upwelling regimes. 1. How does the temporal and spatial variability of the vertical flux and composition of particulate matter vary as it sinks to the sediment surface 2. What is the suitability of various lipids as biological source markers for sediments deeper in the sedimentary record This involves a determination of how much of these compounds survive biological degradation in the water column and surface sediments. 3. What is the relationship between the organic matter composition of sinking particulate material and biological processes in the water column The composition and vertical fluxes of the steroid class compounds are used as an example of how these questions may be answered.

LIPIDS IN AEROSOLS FROM THE TROPICAL NORTH PACIFIC: TEMPORAL VARIABILITY

Robert B. Gagosian, Oliver C. Zafiriou, Edward T. Peltzer and Jane B. Alford

Lipid components in air masses sampled during 1979 at Enewetak Atoll as part of the Sea-Air Exchange Program (SEAREX) were determined to investigate the terrestrial and marine sources and to search for atmospheric transformation processes of oceanic aerosols. Four particulate lipid compound classes (aliphatic hydrocarbons, fatty alcohols, fatty acid esters and salts) all unequivocally show a terrestrial vascular plant source. Their temporal trends correlate moderately well with those of other continental source indicators, such as particulate Al and ^{210}Pb. These particulate lipids originate from wind erosion of Eurasian soil and direct emission from vegetation rather than from biomass burning, anthropogenic sources or evaporation/condensation processes.

A series of apparently marine-derived lower molecular weight alcohols and fatty acid salts and esters are also present. The more typically marine polyunsaturated acids are absent, probably due to their rapid rates of atmospheric degradation. A marine origin for the fatty acid salts $<C_{20}$ requires that marine aerosols be enriched ca. 30-fold over the levels found in surface microlayer samples.

Although particulate total organic carbon data imply major influences of atmospheric transformations on the atmospheric particulate material, these effects are not observed in the lipid class compound distributions.

THE MUSSEL WATCH: INTERCOMPARISON OF TRACE LEVEL CONSTITUENT DETERMINATIONS

W. B. Galloway, J. L. Lake, D. K. Phelps, P. F. Rogerson, V. T. Bowen, J. W. Farrington, E. D. Goldberg, J. L. Laseter, G. C. Lawler, J. H. Martin and R. W. Risebrough

The U. S. National Mussel Watch Program initially used split-sample analyses for interlaboratory quality control purposes. These indicated the possibility of interlaboratory analytical discrepancies as well as problems in the split-sample technique itself. For the third year of the program two mussel homogenates were produced to serve as intercomparison samples, one for metals and organics, the other for radionuclides. The results obtained using these homogenates are encouraging in that generally good agreement is seen among analyses done by several labs in diverse pollutant classes. We conclude from this experience that a quality control program relying on the analysis of large homogeneous samples of the matrix being dealt with is an essential part of any extensive, multi-laboratory program.

PERU UPWELLING REGION SEDIMENTS NEAR 15°S - I. REMINERALIZATION AND ACCUMULATION OF ORGANIC MATTER

Susan M. Henrichs and John W. Farrington

Six sediment cores were obtained along a 70 km transect perpendicular to the Peru coast in the highly productive upwelling region near 15°S, at depths ranging from 90 to 5300 m. All of the sediments sampled were diatomaceous oozes. Three cores overlain by poorly oxygenated water had populations of Thioplocca-like filamentous bacteria in surface sediments. Total organic carbon and total nitrogen contents of the sediments ranged from 0.8 to 10 percent and from 0.1 to 1 percent (dry weight), respectively. For the 90 m and 268 m cores, which had Pb-210 sedimentation rates of about 0.6 and 1.1 cm/yr, organic carbon accumulation rates in surface sediments were 40 and 70gC/m^2-yr. The organic carbon and total nitrogen distributions in the three oxygen minimum zone cores indicate that there have been variations in the rate of accumulation of organic matter over time. These variations may be related in part to the frequency and intensity of El Nino events.

Interstitial water ammonium, nitrate, nitrite, total carbon dioxide, and sulfide concentrations were measured. Remineralization rates in sediments calculated from the dissolved carbon dioxide profiles range from 0.7 to 21 gC/m^2-yr. Rates in cores from water depths of 1430 m and 5300 m were somewhat lower than in oxygen minimum zone sediments, but remineralization rates did not decrease smoothly with depth. Total carbon dioxide concentrations in interstitial waters of two oxygen minimum zone sediments were modeled using both steady-state and non-steady-state distributions of metabolizable organic matter. Oxygen minimum zone sediments had high total carbon dioxide and ammonia concentrations in surface sediment pore waters, which may be due to more rapid remineralization of organic matter near the sediment-water interface.

PERU UPWELLING REGION SEDIMENTS NEAR 15°S - II. DISSOLVED FREE AND TOTAL HYDROLYZABLE AMINO ACIDS

Susan M. Henrichs, John W. Farrington and Cindy Lee

Dissolved free and total hydrolyzable amino acid concentrations were measured in five cores of Peru coastal sediments. The cores were collected along a 70 km transect perpendicular to the coast in the upwelling region near 15°S at depths of 92 m, 268 m, 506 m, 1428 m, and 5300 m. Total hydrolyzable amino acids (THAA) made up 20 to 70 percent of the total nitrogen in these sediments, with the highest proportions in surface sediments of the 92 m, 268 m, and 506 m cores. Variations in THAA content with depth were attributable to a combination of remineralization and varying inputs to the sediment surface over time. The individual amino acid residue composition was remarkably uniform, both with depth in core and between stations.

Dissolved free amino acid (DFAA) concentrations ranged from about 1 μM to more than 200 μM. The highest concentrations were found near the sediment-water interface of sulfide containing sediments. Concentrations generally decreased with depth in sediment. Glutamic acid was a major constituent of nearly all samples, suggesting a bacterial source for most of the DFAA. A nonprotein amino acid, β-aminoglutaric acid, was also a major component, and was the most abundant DFAA below 20 cm depth in the 92 m, 268 m, and 506 m cores. The major trends in DFAA concentration and composition appear to be the net results of biological (largely bacterial) sources and sinks.

CARBONATES AS PETROLEUM SOURCE ROCKS

John M. Hunt and Ann McNichol

Carbonates have frequently been discounted as important source rocks due to their lower organic carbon content and lower catalytic activity compared to shales. However, carbonate source rocks contain mostly sapropelic organic matter which yields a higher percentage of oil earlier than the more humic organic matter of shales. Furthermore, carbonate source-reservoir sequences are frequently overlain by the perfect seal, evaporite, during the time of generation and accumulation. In contrast, many sand-shale sequences tend to leak petroleum during and after accumulation.

The richest source rocks in the world are the argillaceous and siliceous carbonates such as the Green River of Utah, the La Luna of Venezuela and the Nordegg of the Western Canada Basin.

Carbonates like the Austin Chalk of south Texas, which contain 35 to 91 percent

CaCO$_3$, act as both source and reservoir
rock. Light hydrocarbon analyses and pyro-
lysis data both support the concept that
most of the oil in the Austin Chalk is
autochthonous.

FLUXES OF ORGANIC MATTER
INTO THE DEEP OCEAN

V. Ittekkot, W. G. Deuser
and E. T. Degens

The flux of organic matter into the deep
Sargasso Sea, as measured almost continuous-
ly over a period of 44 months by successive
two-month sediment-trap samples, shows sea-
sonal and interannual variations. Detailed
analyses of carbohydrates and amino acids in
the <37 μm fraction of the samples suggest
that the observed fluxes are related to bio-
logical processes in the surface water, and
that zooplankton plays an important part in
the transport of materials to the deep
ocean.

MIGRATION OF C$_1$ TO C$_8$ VOLATILE
ORGANIC COMPOUNDS IN SEDIMENTS FROM
THE DEEP SEA DRILLING PROJECT,
LEG 75, HOLE 530A, WALVIS RIDGE

John P. Jasper, Jean K. Whelan and
John M. Hunt

The distribution of C$_1$ to C$_8$ hydrocar-
bons in sediment samples from DSDP Leg 75,
Hole 530A indicates that significant amounts
of methane and ethane have migrated from
organic rich to organic lean shales in close
proximity. Most compounds larger than
ethane are not migrating out of black shales
where they occur in high concentrations.
These results lead to a general model for
assessing migration. In addition, three
shale types are identified on the bases of
organic carbon and pyrolysis products and
patterns.

VARIATIONS IN ORGANIC MATTER IN A
TIME-SERIES SEDIMENT TRAP

Cindy Lee, Stuart G. Wakeham and
John W. Farrington

A time-series sediment trap was used to
collect material for organic geochemical
analyses as part of the Sediment Trap Inter-
comparison Experiment. The flux of particu-
late matter was related to a change in cur-
rent direction during the course of the ex-
periment rather than to small-scale changes
in surface productivity. Of the compounds
we measured, the n-alkanes reflected this
change the most dramatically, decreasing
with the change in current direction.

Amino acid and lipid components were
measured in the samples. Amino acids made
up 15-35 percent of the total organic carbon
flux and 35-75 percent of the total organic
nitrogen flux collected in the traps. Spe-
cific amino acids indicative of bacterial
biomass or activity suggested that micro-
bial growth occurred in the traps. However,
the effect of this growth on the bulk compo-
sition of particulate matter appeared to be
minimal.

The amino acid distribution of particu-
late organic material collected by large
volume filtration (LVFS) was not signifi-
cantly different from the sediment trap
material, except that the LVFS material did
not appear to be affected by bacterial
growth.

DOWNWARD TRANSPORT OF PARTICULATE MATTER
IN THE PERU COASTAL UPWELLING: ROLE OF
ANCHOVETA, ENGRAULIS RINGENS

Nick Staresinic, John W. Farrington,
Robert B. Gagosian, C. Hovey Clifford
and Edward M. Hulburt

Anchoveta fecal material links produc-
tion and sedimentation of particulate mat-
ter, including organic carbon, organic
nitrogen and diatom frustules, in the
Peruvian coastal upwelling ecosystem. Long-
term fluctuations in anchoveta stock could,
therefore, affect the quantity and composi-
tion of particulate matter input to the
benthos and thereby to the sediment record.

EFFECT OF HYDROCARBON VOLATILITY AND ABSORPTION ON SOURCE-ROCK PYROLYSIS

Martha E. Tarafa, John M. Hunt and Inger Ericsson

Petroleum source rock evaluations by pyrolysis are based on the concept that free hydrocarbons in rock samples are volatilized below 300°C while hydrocarbons cracked from kerogen come off at higher temperatures. The pyrolysis of pure hydrocarbons with different mineral matrices shows that free hydrocarbons containing 16 or more carbon atoms may not be evolved below 300°C, but at varying higher temperatures. The extent to which this occurs depends on the hydrocarbon volatility, the mineral matrix and the pyrolysis instrument design. Source rock parameters which use the P_1 (S_1) peak may not be reproducible between instruments if the rock contains appreciable amounts of high molecular weight hydrocarbons.

LIPID COMPOSITION OF COASTAL MARINE SEDIMENTS FROM THE PERU UPWELLING REGION

J. K. Volkman, J. W. Farrington, R. B. Gagosian and S. G. Wakeham

The compositions of several lipid classes extracted from coastal sediments from the upwelling area at 15°S off Peru have been studied using capillary gas chromatography-mass spectrometry. Many of the sedimentary lipids originate from autochthonous sources in the water column as shown by comparison with the lipid composition of large particles trapped by free drifting sediment traps deployed in the same area. A major mechanism by which many of these labile compounds reach the sea floor appears to be by incorporation into fast sinking anchoveta and zooplankton fecal pellets.

Detailed compositional data are presented for the hydrocarbon and acyclic ketone fractions. The hydrocarbons in the surface sediments show a predominance of branched acyclic C_{25} polyunsaturated alkenes of presumed planktonic origin with smaller concentrations of long-chain n-alkanes. The latter show little odd-predominance in offshore sediments in contrast to inshore sediments where a higher-plant contribution can be recognized. The ketone fractions contain significant amounts of very long-chain unsaturated C_{37}-C_{39} ketones which may originate from the marine alga Emiliania huxleyi. These compounds are also abundant in the sediment trap particulates. Small amounts of C_{23}-C_{35} n-alkane-2-one are present in those sediments containing n-alkanes of higher-plant origin but not in sediments further offshore. The data support earlier suggestions that these compounds may be indirect markers for terrigenous organic matter, but sources in addition to in situ oxidation of n-alkanes are required to explain the distributions observed. The C_{18} isoprenoid ketone 6,10,14-trimethylpentadecane-2-one is abundant in both surface and sub-surface sediments and presumably arises from degradation of phytol. Its concentration is also high in the sediment traps implying a rapid formation in the water column.

MESOCOSM EXPERIMENTS TO DETERMINE THE FATE AND PERSISTENCE OF VOLATILE ORGANIC COMPOUNDS IN COASTAL SEAWATER

Stuart G. Wakeham, Alan C. Davis and Jennifer A. Karas

Studies were carried out in experimental marine ecosystems to determine the fate and persistence of a series of volatile organic compounds in coastal seawater. A suite of aliphatic hydrocarbons, aromatic hydrocarbons, chlorinated C_2-hydrocarbons and chlorinated aromatic hydrocarbons, covering a wide range of water solubilities, volatilities, and susceptibilities to biological degradation, were added to the water column of the mesocosms at concentrations typical of a moderately polluted estuary (0.2-4µg/L). Concentrations in the water column were followed for up to 2 months, under experimental conditions simulating winter, spring, and summer. Water column half-lives of the same compounds ranged from ~ 1 day to up to 4 weeks, depending on season and compound class. Volatilization appears to be the major process removing aromatic hydrocarbons, chlorinated C_2-hydrocarbons, and chlorinated aromatic hydrocar-

bons during all seasons, with biodegradation also important for aromatic hydrocarbons in summer. Aliphatic hydrocarbons are quickly sorbed onto particulate matter and thus removed from the "volatile" pool; biodegradation also affects the alkanes.

FATTY ACIDS, WAX ESTERS, TRIACYLGLYCEROLS AND ALKYLDIACYLGLYCEROLS ASSOCIATED WITH PARTICLES COLLECTED IN SEDIMENT TRAPS IN THE PERU UPWELLING

Stuart G. Wakeham, John W. Farrington and John K. Volkman

Marine particulate matter samples were collected in free-drifting sediment traps in the Peru upwelling region to assess the vertical flux and organic composition of lipids associated with particles sinking out of the euphotic zone. Fatty acids of total hexane-soluble lipids, wax esters, triacylglycerols, and alkyldiacylglycerols were determined in a set of four sediment traps deployed at 14 m and at 52 m during a diel cycle. Fluxes of specific organic compound classes show much greater variations than for bulk particulate organic carbon (POC). Total fatty acids accounted for about 2 percent of the daytime POC flux, but up to 10 percent of the nocturnal POC flux. The maximum fatty acid flux was measured in the 14 m night trap. The composition of the fatty acids was indicative of a mixed phytoplankton/zooplankton source. The flux of particulate 16:0 calculated to be sinking across 52 m based on sediment trap data is 20-fold greater than the estimated accumulation rate in the sediments, indicating that a large portion of this fatty acid is altered either in the water column below 52 m or at the sediment/water interface. Wax esters, triacylglycerols, glyceryl ethers all contain esterified fatty acids, but show flux and compositional trends different from total fatty acids, as well as from each other. Wax ester fluxes into the night 14 m trap were nearly 25 times greater than fluxes into the other three traps, and can be attributed in part to entrapment of live euphausiids in the shallower night trap. Triacylglycerols were about an order of magnitude more abundant in the night traps compared to the day traps. The dominant source of triacylglycerols into the day traps probably is phytodetritus. However, it appears that different zooplankton communities, one active above 14 m and one between 14 and 52 m, are significant triacylglycerol sources to the two night traps. Alkyldiacylglycerols, most likely containing a phytanyl ether moiety,

were only found in the 14 m trap at night. The close correspondence between wax esters and alkyldiacylglycerols suggests a related source.

DISTRIBUTIONS AND FATE OF VOLATILE ORGANIC COMPOUNDS IN NARRAGANSETT BAY, RHODE ISLAND

Stuart G. Wakeham, Jeffrey T. Goodwin and Alan C. Davis

A wide range of volatile organic compounds have been measured in the water column along a transect in Narragansett Bay, Rhode Island, during two summers and two winters. The dominant volatile compounds are chlorinated C_2-hydrocarbons, chlorobenzenes, and aromatic hydrocarbons. Major sources for these anthropogenic compounds are municipal and industrial wastewaters discharged into the upper bay. Concentration trends along the transect are variable depending on the compound class at the time of sampling, indicating that different processes control the distributions of different compounds. Volatilization apparently is a major removal process for all volatile organic compounds. Calculations suggest volatilization halflives of 100-200 hr. in Narragansett Bay. Biodegradation, particularly in summer, is important for aromatic hydrocarbons, which are degraded in a few days. Sorption onto particulate matter and eventual sedimentation is minor, except for the higher molecular weight alkanes.

VOLATILE ORGANIC COMPOUNDS IN NARRAGANSETT BAY, RHODE ISLAND

Stuart G. Wakeham, Jeffrey T. Goodwin and Alan C. Davis

Volatile organic compounds (VOC) have been determined in Narragansett Bay, Rhode Island, water samples as part of an investigation into the sources, fates, and transport of volatile organic compounds in estuarine and coastal seawater. This report

tabulates the concentrations of a wide range of VOC along a transect in Narragansett Bay for two summer and two winter sampling cruises.

ANALYSES OF ORGANIC PARTICULATES FROM BOSTON HARBOR BY THERMAL DISTILLATION-PYROLYSIS

Jean K. Whelan, Michael G. Fitzgerald and Martha E. Tarafa

The techniques of thermal distillation and pyrolysis coupled with gas chromatography (GC) and GC-mass spectrometry (GCMS) provide a "fingerprint" of the organic matrix of particulates collected from Boston Harbor. Pyrolysis products of particles caught in sediment traps closely resemble those of bottom sediments and are similar to those of some species of phytoplankton. GCMS analyses indicate that these organic matrices are all lipid rich, though the lipid in the seston appears to be distinct from that in both sediment-trap and phytoplankton samples. None of these samples resemble the sewage sludge dumped into the area, suggesting rapid reworking or remineralization of the sludge material.

VOLATILE C_1-C_7 ORGANIC COMPOUNDS IN AN ANOXIC SEDIMENT CORE FROM THE PETTAQUAMSCUTT RIVER (RHODE ISLAND, USA)

Jean K. Whelan, Mary A. Hinckley and John M. Hunt

Surface sediments from an anoxic marine environment, the Upper Basin of the Pettaquamscutt River, Rhode Island, were analyzed for volatile organic compounds in the C_1 to C_7 range. The compounds identified included methane, ethane, alkenes (C_2-C_5), carbon disulfide, cyclopentane, 3-methylpentane, methylfuran, aldehydes and ketones. Ethane, methylfuran, and most of the aldehydes and ketones showed maxima at the sediment water interface. Methane levels were very high - 10 to 100 times greater than observed in most other surface sediments examined in this laboratory.

VOLATILE C_1-C_8 ORGANIC COMPOUNDS IN SEDIMENTS FROM THE PERU UPWELLING REGION

Jean K. Whelan and John M. Hunt

Volatile C_1-C_8 organic compounds were analyzed in seven cores recovered from a transect across the Peru Shelf upwelling region. Compounds detected in ng/g dry weight quantities included methane, ethane, propane and other C_4-C_7 alkanes as well as functionalized compounds including alkenes, furans and aldehydes. Strong correlations were observed between some groups for compounds with similar structures. Maxima in two groups of compounds were observed: 1) C_1, C_2, C_3, furans, and butanals (plus sporadic alkanes) as nitrate levels decreased below about 2-4 μM in the subsurface and 2) C_4-C_6 alkenes together with predominantly branched and cycloalkanes at the sediment-water interface in cores recovered from oxygenated bottom waters. The levels of C_1-C_7 alkanes in these sediments are comparable to levels found in DSDP cores buried to depths of less than 600 m (or not exposed to geothermal temperatures exceeding about 30°C).

VOLATILE ORGANIC COMPOUNDS IN MACROALGAE

J. K. Whelan, M. E. Tarafa and J. M. Hunt

Nutrient enriched red algae (Gracilaria) contain more than a milligram per gram dry weight of a bicyclooctane and bicycloheptane presumably derived from a sesquiterpene precursor. Nutrient deprived Gracilaria contain only microgram quantities of these alkanes, but increased amounts of volatile furans, ketones and aldehydes. Eight other C_4 through C_8 hydrocarbons were found in algae with n-pentane occurring in four species. These results provide a source for some of the volatile organic compounds identified in recent marine sediments.

S E A W A T E R   A N D
G E O C H E M I S T R Y

SEDIMENTOLOGICAL RECONSTRUCTION OF THE RECENT PATTERN OF MERCURY POLLUTION IN THE NIAGARA RIVER

Ronald J. Breteler, Vaughan T. Bowen, Richard Henderson and David L. Schneider

Since 1952 there have been a number of sharp changes in the rates of delivery, or in the ratios delivered, of several long-lived artificial radionuclides distributed worldwide from atmospheric nuclear tests. Analyses of the nuclides in suitably selected, and collected, aquatic sediment cores indicate several dated horizons that can yield more refined estimates of recent sedimentation history than are otherwise available. This approach has been applied to several cores in eastern Lake Erie, the Niagara River and its delta in Lake Ontario, and a selection of the sediments so dated have been analyzed for total mercury. This history of Hg pollution in the Niagara River developed in this way shows very little evidence of the local Niagara Falls Hg input from chloralkali plant operation until the 1930's. Between 1940 and 1950, the local input increased 10-20 fold and continued to increase to a maximum in 1952-54, after which it fell by 50 percent and held uniform until 1970. The effect of corrective measures taken in 1970 was evident by 1971-72, and by 1979 the mercury concentrations in sediments deposited in both the Niagara River delta and the U. S. pumped storage reservoir had been reduced by approximately an order of magnitude below 1970 concentrations; half of the 1979 increment can be attributed to transport from Lake Erie.

RARE EARTH DISTRIBUTIONS WITH A POSITIVE CERIUM ANOMALY IN THE WESTERN NORTH ATLANTIC OCEAN

H. J. W. De Baar, P. G. Brewer and M. P. Bacon

From the vertical distributions of the rare earth elements (REE) in the Sargasso Sea we now report the first profiles of Pr, Tb, Ho, Tm and Lu in seawater, together with profiles for La, Ce, Sm, Eu and Yb. The first observations of positive cerium anomalies in seawater are ascribed to reducing inshore sediments as a source for Ce. All vertical profiles are consistent with adsorption of trivalent rare earths by settling particles, possibly siliceous or calcareous, followed by their release at or near the seafloor on dissolution of the carriers. The very different Ce profile demonstrates the additional effects of oxidation-reduction reactions.

In press: Nature.

DECADE TIMESCALE VARIATIONS OF $^{14}CO_2$ EXCHANGE BETWEEN ATMOSPHERE AND OCEAN

Ellen M. Druffel

Radiocarbon measurements reported in tree rings and in Gulf Stream corals for the past 30 years are correlated to obtain the rate of net input of $^{14}CO_2$ from atmosphere to ocean. The average value for this input is 8 percent/year of the prevailing $^{14}C/^{12}C$ difference between atmosphere and ocean. This net input rate appears to vary by a factor of two over a period of 20 years. These observations correlate with changes in the rate of water mass renewal noticed by Jenkins (1982) in the Sargasso Sea.

LONG TERM VARIABILITY OF TEMPERATURE AND RADIOCARBON IN THE GULF STREAM: OCEANOGRAPHIC IMPLICATIONS

Ellen M. Druffel

Variability in temperature and in radiocarbon levels are recorded in coralline aragonite that grew in the Gulf Stream during the past four centuries. In particular, $^{18}O/^{16}O$ ratios reflect a decrease of about 1°C in surface water temperature during the latter part of the Little Ice Age. Radiocarbon levels also rose in the surface waters of the Gulf Stream as did those levels in atmospheric CO_2 during the Maunder minimum. These observations indicate that ocean circulation may have been significantly different in the North Atlantic around the beginning of the 18th century.

In press: Radiocarbon.

TIME HISTORY OF HUMAN GALLSTONES: APPLICATION OF THE POST-BOMB RADIOCARBON SIGNAL

Ellen M. Druffel and Henry Y. I. Mok

Bomb-produced radiocarbon is a valuable tool for studying rates of short-term processes involving carbon cycling. This study shows that bomb ^{14}C is an excellent tracer of a biochemical process that takes place in the human body, namely the accretion of stones in the gallbladder. The methods developed for obtaining time histories of $^{14}C/^{12}C$ and $^{13}C/^{12}C$ in concentric layers from a large gallstone (30 mm diameter) are reported. Formation times are assigned by matching the $^{14}C/^{12}C$ obtained from individual layers with those found for known-aged tree rings. Results show that the gallstone grew over a period of 8 years and seems to have lain dormant within the gallbladder for a period of 11 years. The average growth rate was 1.6 cm^3/year and appears to have been relatively constant throughout the entire growth period. Comparison of these results with those from other stones collected from several other symptomatic and asymptomatic patients is presented.

A DEAD CENTRAL AMERICAN CORAL REEF TRACT: POSSIBLE LINK WITH THE LITTLE ICE AGE

Peter W. Glynn, Ellen M. Druffel and Robert B. Dunbar

Radiocarbon analyses, stable isotopic measurements and extensive field observations were made of coral reefs off the Pacific coast of Costa Rica and Panama. These analyses showed that live coral reefs in the Gulf of Papagayo, Costa Rica, were severely depleted in number, size and variety of species, compared to reefs in the major upwelling zone of the Gulf of Panama. Coral growth in the Gulf of Papagayo consisted mainly of dead reefs that died during the latter part of the Little Ice Age (150 to 300 years B.P.). The $\delta^{18}O$ records revealed that most of the dead reefs were exposed to relatively cool water immediately preceding death. We propose that during the Little Ice Age and, to a much greater extent during the last major glaciation, there was an equatorward shift of the Northern Trade Wind system, which caused an intensification of upwelling at lower latitudes. This increased upwelling was the likely cause of the demise of coral reefs in the Gulf of Papagayo.

PETROLOGY AND GEOCHEMISTRY OF ROCKS FROM THE ANGOLA BASIN ADJACENT TO THE WALVIS RIDGE: DSDP LEG 75, SITE 530

Susan E. Humphris and Geoffrey Thompson

DSDP Leg 75 drilled into igneous basement in the Angola Basin at Site 530, located about 20 km north of the escarpment at the eastern end of the Walvis Ridge. Petrographic and geochemical characteristics of the basalts indicate that the basement is quite uniform, with any variation in chemical composition being related to weathering, crystal fractionation, and the modal abundances of individual minerals.

These basalts are similar to those drilled at Sites 527 and 528 on the central section of the Walvis Ridge, but are less enriched in incompatible elements than basalts dredged from the eastern end of the Walvis Ridge. They show distinct compositional differences from mid-ocean ridge basalts, which suggests that the Walvis Ridge hot spot has influenced the basement of the southern part of the Angola Basin. Comparison of the chemistry of the Site 530 basalts with basalts drilled during Leg 74, indicates that the implied variation in mantle source is not in accord with any simple along-ridge progression, but may be related to vertical zonation within the volcanic pile.

OXYGEN UTILIZATION RATES IN NORTH ATLANTIC SUBTROPICAL GYRE AND PRIMARY PRODUCTION IN OLIGOTROPHIC SYSTEMS

William J. Jenkins

Oxygen utilization rates (OUR) have been determined by tritium-^{3}He dating in a 1000 km on-a-side triangular area in the subtropical North Atlantic. The results, around 0.15 to 0.20 ml/l/y agree well with previous estimates. Integration of the depth-OUR values below the euphotic zone gives a net water column oxygen consumption rate of 5.7 moles/m^2/y which corresponds to a flux of 55±5 g carbon/m^2/y out of the euphotic zone. This implies that sur-

face primary production may be several hundred grams of carbon/m^2/y, suggesting that ^{14}C assimilation techniques have grossly underestimated true "oligotrophic" primary production.

TROPOSPHERIC NO$_x$ AND O$_3$ BUDGETS IN THE EQUATORIAL PACIFIC

Shaw C. Liu, Mack McFarland, Dieter Kley, Oliver C. Zafiriou and Barry Huebert

By combining the results of model calculations and simultaneous measurements of O$_3$, NO, HNO$_3$, particulate NO$_3$, and meteorological parameters in the mid-Pacific, we have investigated the budget and photochemistry of near surface atmospheric ozone and odd nitrogen. The observed decrease of O$_3$ toward the Intertropical Convergence Zone is consistent with the transport of O$_3$ by the reaction between H$_2$O and O(^{1}D). The total deposition flux of odd nitrogen deduced from the data is about 1.3×10^9 cm^{-2}s^{-1}, or 5 MT(N)/yr averaged globally. Most of the deposition flux is due to HNO$_3$ and particulate NO$_3$. This deposition flux is probably representative of values over most of the Pacific because the HNO$_3$ and particulate NO$_3$ densities measured over the Pacific during the GAMETAG experiments are consistent with our values. Since the residence time of odd nitrogen in the lower troposphere is short, a widely distributed, diffuse source of odd nitrogen is required to balance the deposition flux. It seems that the NO formed by cloud to cloud lightning in the tropical upper troposphere is the most likely source.

RADIOCARBON IN THE WEDDELL SEA AS SEEN IN A DEEP-SEA CORAL AND KRILL

Robert L. Michel and Ellen M. Druffel

Radiocarbon measurements were performed on krill and coral samples from the Weddell Sea. These are the first radiocarbon measurements available from the Weddell Sea since 1973. These data reveal $^{14}C/^{12}C$ in Weddell surface waters and southern Weddell Shelf water. These data indicate that the radiocarbon levels in surface waters in 1980 were the same or slightly lower than those present in 1973. In addition, an unusually low $\Delta^{14}C$ value for shelf water (from coral) at 500 m is evidence that Warm Deep Water (WDW) may penetrate much further and more frequently onto the shelf region than had previously been expected.

HYDROTHERMAL PROCESSES AT SEAFLOOR SPREADING CENTERS: APPLICATION OF BASALT-SEAWATER EXPERIMENTAL RESULTS

Michael J. Mottl

Both the chemistry of seafloor hot springs and the chemical changes exhibited by basalts during alteration to greenschist facies assemblages have been accurately predicted by laboratory experiments reacting seawater with basalt. Although the experiments were run as an isothermal, closed-system batch process, they largely succeeded in duplicating the products of the natural open-system, continuous flow process. For the solutions, this resulted mainly from rapid reaction rates at high temperature, relative to flow rates in the natural systems, so that equilibrium with the secondary mineral assemblage represented a significant control on solution composition both in the experiments and in nature. For the rocks, it resulted from a similar alteration history in which largely unreacted seawater reached greenschist facies temperatures before reacting with the basalts, and from element exchanges between rock and solution which were coupled via charge balance constraints so that the batch process in the experiments simulated the incremental process in nature.

The key concept in relating the batch process to the incremental process is the seawater/rock ratio, which because of the nature of the chemical exchanges involved can best be estimated from the uptake of seawater Mg by the altered rock. The experiments predict a systematic change in rock chemistry and mineralogy as alteration proceeds to higher seawater/rock ratios. The prediction is borne out for the fluxes of Mg and Ca, the flux directions of Na, Si and Mn, and the mineral abundances of chlorite, quartz, and actinolite. It is not borne out for the Fe flux, the magnitude of the Na flux, and the abundances of albite and epidote, because the experiments failed as batch processes to allow for local redistribution of elements via diffusion. This latter process is important in altered rocks

from the natural systems for Fe^{2+}, which diffuses into zones where chlorite is forming preferentially due to influx of seawater Mg, and for Na^+, which accumulates as albite in zones of lesser Mg influx, in exchange for Ca.

ELEMENTAL AND STABLE ISOTOPIC COMPOSITION OF PORE WATERS AND CARBONATE SEDIMENTS FROM DSDP SITES 501/504 AND 505

Michael J. Mottl, James R. Lawrence and Lloyd D. Keigwin

Two sites were drilled on the southern flank of the Costa Rica Rift on IPOD Legs 68/501 and 69, one on 3.9 m.y. old crust which is effectively cooled by seawater circulation through basement, and the other on 6.2 m.y. old crust which has been sealed by sediment and reheated to 60-120°C within the upper 560 m of basement.

Although sediment thicknesses at the two sites are similar (150-240 m vs. 270 m), the much rougher basement topography at the younger Site 505 produces occasional basement outcrops, through which 80-90 percent of the total heat loss apparently occurs by advection of warm seawater. This seawater has been heated only slightly, as indicated by a temperature of only 7-8°C at the base of the sediments. Changes in its composition due to reaction with basement basalts have been largely negligible, as indicated by profiles of sediment pore water chemistry. Bacterial sulfate reduction in the sediments produces a decrease in SO_4 (and Ca) and an increase in alkalinity (and Sr, NH_3) with depth, but these trends reverse and all of these species plus Mg, K, Na, and chlorinity approach seawater values near basement. Si, however, is higher and Li may be lower.

At the older Site 501/504, where heat loss is entirely by conduction, the basement contact is at 59°C. Sediment pore water chemistry is heavily affected by reaction with basaltic basement, as indicated by large decreases in $\delta^{18}O$, Mg, alkalinity, Na, and K and an increase in Ca with depth. The size of the changes in Ca, Mg, alkalinity, Sr, $\delta^{18}O$, and SO_4 varies laterally over 500 m, indicating lateral gradients in pore water chemistry nearly as large as the vertical gradients. The lateral gradients are believed to result from similar lateral gradients in the composition of the basement formation water, which are propagated through the sediments by diffusion.

Modeling of the $\delta^{18}O$ profile suggests that the basement at Site 501/504 became sealed to rapid advection so that reaction rates began to dominate the basement pore water chemistry about one million years ago. A limestone-chert diagenetic front has moved upward through the lower sediments only in the last 200,000 years or less.

ADVECTION OF PORE FLUIDS THROUGH SEDIMENTS IN THE EQUATORIAL EAST PACIFIC

F. L. Sayles and W. J. Jenkins

Measurements of $^4He/^3He$ and Ca^{2+} in the pore waters of sediments at two locations in the Eastern Equatorial Pacific indicate that solution advection is occurring through the sediments. Both $^4He/^3He$ and Ca^{2+} yield velocity values for advective flow of about 20 cm/yr. Mass balance constraints are also consistent with the interpretation presented. Flow appears to be occurring through relatively thick sediments - on the order of 300 m.

THE CONTRIBUTION OF THE GREENLAND AND BARENTS SEAS TO THE DEEP WATER OF THE ARCTIC OCEAN

James H. Swift, Taro Takahashi and Hugh D. Livingston

The deep waters of the Arctic Ocean are traditionally held to be fed by an influx of Norwegian Sea Deep Water (NSDW) via the northward-flowing West Spitsbergen Current. Discrete sample and CTD observations obtained from the Greenland-Spitsbergen Passage in August 1981 during the Transient Tracers in the Ocean (TTO) North Atlantic expedition showed a ~ 100 m thick layer of Greenland Sea Deep Water (GSDW: colder and fresher than NSDW) at 2500 m, spreading northward along the bottom of a deep, unimpeded channel, underneath the NSDW. Since

the available data indicate that Arctic Ocean Deep Water (AODW) has a higher salinity than NSDW, mixing of NSDW and GSDW cannot produce AODW. Therefore, other sources, such as the peripheral Arctic shelf seas, must contribute dense saline water to the Arctic Ocean. Concentrations of ^{137}Cs and ^{90}Sr observed in AODW are greater than those observed in GSDW and NSDW. The concentrations of these radionuclides on the Barents Sea shelf are sufficiently high and in the correct relative proportions to support this proposition.

AIR-SEA FLUXES OF TRANSIENT ATMOSPHERIC SPECIES

Anne M. Thompson and Oliver C. Zafiriou

The air-to-sea fluxes of the major reactive tropospheric gases and radicals have been estimated from the two-layer stagnant film model using measured or modeled concentrations and taking into account effects of species solubility and chemical reactivity on the exchange rate. Nearly all of the transfers appear to be limited by diffusion through the gas phase. The largest fluxes are associated with acids (HNO_3, HCl) and the more abundant molecular and radical transients in the atmosphere (O_3, H_2O_2, CH_3OOH, HO_2, CH_3O_2). For the acids and other soluble gases, e.g., H_2O_2, H_2CO, addition of rainout and near-surface particulate sinks reduce the calculated air-sea (dry) fluxes up to a factor of 2.

The atmospheric input to the ocean is smaller than estimated surface water in situ production for most species considered. Exceptions are NO_3, CH_3OOH and CH_3O_2, for which the atmospheric source exceeds plausible oceanic sources.

In contrast to the bulk aqueous and gas phases it appears that the chemistry of the interfacial layer at the sea surface is significantly influenced by the influx of radicals and reactive oxidants. Indeed, although a basic assumption of the two-film model is that microlayer reactions affect only the exchange rate, they may be sufficiently intense to chemically modify the diffusing gases.

HYDROTHERMAL FLUXES IN THE OCEAN

Geoffrey Thompson

In this chapter we will examine the potential of the seawater-basalt reaction as a major source and sink for various ions in seawater. A variety of observations and measurements relevant to the extent, magnitude and directions of exchange during seawater-oceanic basement reaction will be reviewed. In the light of these observations and evidence, some of the major controls influencing the fluxes will be considered. It is important to realize that this process is not yet fully understood or the fluxes well known. In one sense it is a little premature to present a review of an active ongoing area of research in chemical oceanography. Nevertheless the implication of the seawater-oceanic basement reaction and subsequent rates of exchange of ions is far reaching and deserves close scrutiny. Thus this chapter is more a statement concerning the state-of-the-art of these studies than a conclusive review.

PETROLOGY AND GEOCHEMISTRY OF ROCKS FROM THE WALVIS RIDGE: DSDP LEG 74, SITES 525, 527 AND 528

Geoffrey Thompson and Susan E. Humphris

DSDP Leg 74 drilled basement on the Walvis Ridge at Sites 525, 527 and 528. These sites are located on the crest and flanks of a segment of the Ridge about 68 to 70 million years old in the central province of the Ridge. Each site has a number of distinct subaqueous flows separated by sediment layers. Variation in geochemistry between units and between sites is in part related to alteration or crystal fractionation, but in part must be related to small scale compositional variation in the mantle source of the basalts.

These Leg 74 basalts are similar to other basalts recovered from the Walvis Ridge and the Rio Grande Rise. They show distinct compositional differences to mid-ocean ridge basalts in general, and to those recovered from the South Atlantic at this latitude, and also to basalts presently erupting in Tristan da Cunha. The composition of the Walvis Ridge basalts does not suggest simple mixtures of present day MORB and Tristan da Cunha melts. If the Walvis Ridge represents the trace of the Tristan da Cunha hot spot as the plates separated, then the composition of the mantle source

has differed at different times in the past, suggesting mantle heterogeneity.

R A D I O C H E M I S T R Y

REMOVAL OF ^{230}Th and ^{231}Pa AT OCEAN MARGINS

R. F. Anderson, M. P. Bacon and P. G. Brewer

Uranium, thorium and protactinium isotopes were measured in particulate matter collected by sediment traps deployed in the Panama Basin and by in situ filtration of large volumes of seawater in the Panama and Guatemala Basins. Concentrations of dissolved Th and Pa isotopes were determined by extraction onto MnO_2 adsorbers placed in line behind the filters in the in situ pumping systems.

Concentrations of dissolved ^{230}Th and ^{231}Pa in the Panama and Guatemala Basins are lower than in the open ocean, whereas dissolved ^{230}Th/^{231}Pa ratios are equal to, or slightly greater than, ratios in the open ocean. Particulate ^{230}Th/^{231}Pa ratios in the sediment trap samples ranged from 4-8, in contrast to ratios of 30 or more at the open ocean sites previously studied. Particles collected by filtration in the Panama Basin and nearest to the continental margin in the Guatemala Basin contained ^{230}Th/^{231}Pa ratios similar to the ratios in the sediment trap samples. The ratios increased with distance away from the continent.

Suspended particles near the margin show no preference for adsorption of Th or Pa and therefore must be chemically different from particles in the open ocean, which show a strong preference for adsorption of Th. Ocean margins, as typified by the Panama and Guatemala Basins, are preferential sinks for ^{231}Pa relative to ^{230}Th. Furthermore, the margins are sinks for ^{230}Th and, to a greater extent, ^{231}Pa transported by horizontal mixing from the open ocean.

REMOVAL OF ^{230}TH AND ^{231}PA FROM THE OPEN OCEAN

R. F. Anderson, M. P. Bacon and P. G. Brewer

Concentrations of ^{230}Th and ^{231}Pa were measured in particulate matter collected by sediment traps deployed in the Sargasso Sea (Site S_2), the north equatorial Atlantic (Site E), and the north equatorial Pacific (Site P) as well as in particles collected by in situ filtration at Site E. Concentrations of dissolved Th and Pa were determined by extraction onto manganese dioxide adsorbers at Site P and at a second site in the Sargasso Sea (Site D).

Dissolved ^{230}Th/^{231}Pa activity ratios were 3-6 at Sites P and D. In contrast, for all sediment-trap samples from greater than 2000 m, unsupported ^{230}Th/^{231}Pa ratios were 22-35 (average 29.7). Ratios were lower in particulate matter sampled at shallower depths. Particles filtered at 3600 m and 5000 m at Site E had ratios of 50 and 40. Results show that suspended particulate matter in the open ocean preferentially scavenges Th relative to Pa. Most of the ^{230}Th produced by decay of ^{234}U in the open ocean is removed by adsorption to settling particulate matter. In contrast, less than 50 percent of the ^{231}Pa produced by decay of ^{235}U is removed from the water column by this mechanism. Mixing processes transport the remainder to other sinks.

GLACIAL TO INTERGLACIAL CHANGES IN CARBONATE AND CLAY SEDIMENTATION IN THE ATLANTIC OCEAN ESTIMATED FROM THORIUM-230 MEASUREMENTS

Michael P. Bacon

The cause of the climatically controlled fluctuations in the carbonate content of deep-sea sediments remains the subject of uncertainty and debate. Three variables are involved: supply of biogenic carbonate, loss by dissolution, and dilution by non-carbonate phases. It is suggested that ^{230}Th, which is produced in the ocean at a constant rate, provides a reliable reference for measuring variations in rate of sedimentation on a regional scale. Results of a preliminary analysis based on published data indicate that, for depths at and above the lysocline, the carbonate fluctuations

observed in cores from the North Atlantic are due primarily to variations in the terrigenous clay input, which was 2-5 times higher during glacials than during interglacials. Carbonate deposition appears to have been somewhat reduced during glacials, but probably not by more than a factor of two. From published $^{230}Th/^{232}Th$ profiles it appears that the South Atlantic also received increased inputs of terrigenous clay during glacial periods.

INTERCOMPARISON OF ^{210}Pb MEASUREMENTS AT GEOSECS STATION 500 IN THE NORTHEAST PACIFIC

Y. Chung, R. Finkel, M. P. Bacon, J. K. Cochran and S. Krishnaswami

During reoccupation of the GEOSECS-I test station in May 1979, more than eighty 30-liter Niskin samples were collected in profile, many as replicates, for ^{210}Pb intercomparison measurements by the WHOI, SIO and Yale groups. In addition to the inter-laboratory comparisons, the SIO group also carried out extensive experiments to test the effect of sample scavenging method, Pb equilibration time (storage effect), and filtration process on the measured ^{210}Pb results.

The intercomparison measurements indicate that there is a general agreement between the various sets of data. The sample set which allows a direct comparison at the same depth was available in most cases only between two of the three groups. The direct paired comparison shows that i) the WHOI data are systematically 3 percent lower than the SIO data; ii) there are no systematic differences observed between the SIO and Yale data although the scatter is rather large; iii) the Yale data are systematically higher than the WHOI data by about 8 percent.

The SIO experiments show that i) the two scavenging methods employed ($Fe(OH)_3$ and Co-APDC co-precipitation) yield identical ^{210}Pb results; ii) variation of Pb carrier equilibration time or of storage time has no discernible effect; iii) the filtration apparatus and procedure employed at this station do not result in ^{210}Pb loss or contamination.

The ^{210}Pb profile structure and absolute concentration measured earlier at the same location (GOGO-II test station and GEOSECS station 347) agree with those of station 500 within 10 percent. The present profile shows a minimum ^{210}Pb concentration around 500 m depth, marking the penetration depth of the flux of excess ^{210}Pb from the atmosphere. There is a mild mid-depth maximum around 2500-3000 m. The $^{210}Pb/^{226}Ra$ activity ratio decreases monotonically from about 1 at the ^{210}Pb minimum to about 0.5 near the bottom. The particulate ^{210}Pb profile shows a systematic increase from the subsurface water to the bottom water by a factor of 5. This feature has been observed in many GEOSECS particulate ^{210}Pb profiles.

LABORATORY STUDIES OF RADIONUCLIDE DIAGENESIS IN NEARSHORE SEDIMENTS: II. THE NATURALLY OCCURRING RADIONUCLIDES (U, Ra, Th, and ^{210}Pb)

J. Kirk Cochran, Edward R. Sholkovitz, Anne E. Carey, Lolita D. Surprenant and David L. Schneider

The effects of diagenetic oxidation-reduction reactions on the geochemical behavior of naturally occurring radionuclides in coastal marine sediments have been investigated using experimental sediment systems maintained in the laboratory. Small (2700 cm^2) polyethylene tanks filled with muddy sediment free of macrofauna and covered with oxygenated seawater were sampled as a function of depth and time up to a period of 16 weeks. Pore water (0.45μm filtered) uranium concentrations decrease from the overlying water value to a minimum at the depth of the pore water iron maximum (2-4 cm). U concentrations increase with further depth to values greater than the initial pore water concentration and are as high as 7.4 dpm $^{238}U/kg$ after 16 weeks. This observation is consistent with reduction of U followed by complexation and solubilization of the reduced U, possibly in association with ligands like dissolved organic carbon which result from organic matter oxidation. Radium (^{226}Ra) correlates with pore water manganese, with both displaying a maximum in the 0-2 cm depth interval. This pattern suggests that Ra is mobilized in nearshore sediments partly in association with reduction of manganese oxides. Thorium (^{232}Th) concentrations in the pore waters are 10^2 times that of Buzzards Bay, Massachusetts, seawater and 10^4 times published open ocean values. The pore water thorium may be colloidal or its solubility may be enhanced in nearshore sediments in which diagenesis of organic matter is occurring. The pore water concentrations of ^{210}Pb are difficult to distinguish from zero after 7 weeks, probably due to the relative insolubility of Pb sulfide in the sediment. The pore water gradients in U, Ra, and Th result in fluxes into the sediment for U and out for Ra and Th, but

are of insufficient magnitude to affect the solid phase concentrations over the time of the experiment.

HELIUM ISOTOPIC VARIATIONS IN VOLCANIC ROCKS FROM LOIHI SEAMOUNT AND THE ISLAND OF HAWAII

Mark D. Kurz, William J. Jenkins, Stan Hart and David Clague

Helium isotopic ratios ranging from 20 to 32 times the atmospheric $^3He/^4He$ (R_A) have been observed in a suite of 15 basaltic glasses from the Loihi Seamount. These ratios, which are up to four times higher than MORB and more than twice nearby Kilauea, are strongly suggestive of an extremely primitive source of volatiles supplying this volcanism. The Loihi glasses measured spanned a broad compositional range, and the $^3He/^4He$ was found to be generally lower for the alkali basalts than for the thoeliites. The low $^3He/^4He$ component appears to be associated with a olivine xenocryst "phase" within which fluid inclusions are probably the carrier of the contaminant helium. One Loihi sample analyzed showed a much lower isotopic ratio (< 5 R_A), but a combination of low He concentration, high vesicularity, and cracks lined with clay minerals suggests the low ratio is due to gas loss and atmospheric helium contamination.

Crushing and melting experiments show that for modest vesicularities (< 5 percent by volume) the Loihi glasses obey a MORB type partitioning trend, but higher vesicularities show considerably more scatter due to volatile mobilization. The high vesicularities, low extrusion pressure and generally low helium concentrations are consistent with a considerable degree of degassing. Analysis of dunites, plus correlation of bulk analysis concentrations with xenocryst abundances also suggest that xenocrysts are a significant carrier of contamination (low $^3He/^4He$) helium.

Analysis of samples from other Hawaiian volcanoes (Kilauea, Mauna Loa, Hualalai, and Mauna Kea) show a smooth decrease in $^3He/^4He$ with increasing volcano age and volume. We interpret this to be a synoptic picture of the time evolution of a hot-spot diapir: the earliest stage is characterized by primitive (> 30 R_A) helium with some (variable) component of lithospheric contamination incurred during "breakthrough", while the later stages are characterized by a relaxation toward lithospheric $^3He/^4He$ ratios (~ 8 R_A) due to isolation of the diapir from the mantle below (as the plume moves on), and subsequent mining of the inherited helium and contamination from the surrounding lithosphere. The abrupt contrast in $^3He/^4He$ between Kilauea and Loihi, despite their close proximity, is indicative of the small lateral extent of the plume.

LARGE PARTICLE TRANSPORT OF PLUTONIUM AND OTHER FALLOUT RADIONUCLIDES TO THE DEEP OCEAN

Hugh D. Livingston and Robert F. Anderson

Artificial radionuclides introduced to the atmosphere as a consequence of atmospheric nuclear weapons tests have been detected in deep sediments of the Atlantic and Pacific Oceans and of the Mediterranean Sea. The nuclides which have been found in these sediments have half-lives long enough to be detectable 10 or more years after their introduction to the ocean and biogeochemistries which permit particle association and transport. They include such nuclides as $^{239,240}Pu$, ^{238}Pu, ^{241}Am, ^{55}Fe and ^{137}Cs. For fallout nuclides to have been transported to the deep ocean in the two to three decades since they were delivered to the sea surface, relatively rapid transport through the water column is required. Such large, rapidly settling particles as are collectable by sediment traps are clearly capable of providing transport over these timescales. We describe here the results of radiochemical analysis of Pu and other fallout nuclides in three series of sediment trap samples, two in the Pacific and one in the Atlantic, collected as part of the PARFLUX program. The data are used to address the question of the role large particles play in processes which transfer parti-cle reactive artificial radionuclides through oceanic water columns.

RADIONUCLIDES FROM WINDSCALE DISCHARGES
II: THEIR DISPERSION IN SCOTTISH AND
NORWEGIAN COASTAL CIRCULATION

H. D. Livingston, V. T. Bowen
and S. L. Kupferman

Measurement of the concentrations of ^{134}Cs, ^{137}Cs, ^{90}Sr, ^{238}Pu, and $^{239,240}Pu$ in Scottish and Norwegian coastal waters in 1976 and 1978 provides information on dispersal pathways, transport times, and dilution in these waters of radioactive waste discharged to the Irish Sea from the Windscale nuclear fuel reprocessing plant in Cumbria, U. K. Consideration of such nuclide ratios as $^{134}Cs/^{137}Cs$ and $^{137}Cs/^{90}Sr$ both in Windscale discharges and in these coastal waters is shown to be a more powerful tool for transport rate derivation than are the changing concentrations in space and time of individual radionuclides. The soluble radionuclides in the discharges are held in the Irish Sea for about two years, moved relatively rapidly to the North Sea and discharged from there to the Norwegian coastal current, subject in hydrographic regions of the North Sea to residence times which increase from north to south from a few months to less than two years. Dilution in the main Windscale plume between the Irish Sea outflow and North Sea inflow, though variable over the short-term, is estimated to average a factor of three. Certainly by 1978, if not a little earlier, the North Sea outflow in the Norwegian coastal current had begun to be labeled with the increased concentrations of ^{134}Cs and ^{137}Cs resulting from the sharp increase which began in 1974 in their discharges to the Irish Sea.

THE GEOCHEMISTRY OF PLUTONIUM IN FRESH
AND MARINE WATER ENVIRONMENTS

Edward R. Sholkovitz

The chemical behaviour of plutonium in the hydrosphere is a subject of both great practical and intrinsic importance. The production and eventual disposal of Pu and other artificial radionuclides dictate that this be the case. The main objective of this paper is to provide a synthesis and critical examination of currently published data and interpretations on the geochemistry of Pu in natural waters and sediments.

Where appropriate an attempt is made to re-interpret published data with the aim of establishing the relationships between geochemical and biological processes and the distribution, concentration and speciation of Pu. Particular attention is paid to the question of the potential for the chemical remobilization of Pu from the solid to the aqueous phase. Approximately one third of the text deals with freshwaters (mostly lakes) while two thirds discusses the estuarine, coastal and open ocean environments.

THE AQUATIC CHEMISTRY OF PLUTONIUM
IN SEASONALLY ANOXIC LAKE WATERS

E. R. Sholkovitz, A. E. Carey
and J. K. Cochran

Our results from a lake (Gull Pond, Mass.) with a seasonally anoxic hypolimnion show that the oxygen depleted and Fe- and Mn-rich bottom water contains a concentration of filterable $^{239,240}Pu$ which is five times that of the oxygenated surface waters. This feature has been observed in anoxic hypolimnia of other lakes and is convincing evidence that the concentration and speciation of $^{239,240}Pu$ in the water column is significantly influenced by redox cycles of Fe and/or Mn operating in the sediments and within the water column. The possibility that ^{137}Cs and ^{90}Sr and U may also be involved in the redox cycles of lakes cannot be ruled out by our results which show filterable concentrations increasing slightly with depth. Fe-55 data show that this atmospherically delivered artificial radionuclide is a useful indicator of iron redox geochemistry.

LABORATORY STUDIES OF RADIONUCLIDE
DIAGENESIS IN NEARSHORE SEDIMENTS:
I. THE ARTIFICIAL RADIONUCLIDES,
$^{239,240}Pu$, ^{137}Cs, and ^{55}Fe

E. R. Sholkovitz, J. K. Cochran
and A. E. Carey

Controlled laboratory experiments have been used to study the diagenetic chemistry of $^{239,240}Pu$, ^{137}Cs, and ^{55}Fe. Experiments

using Buzzards Bay sediments in small tanks show the rapid development of pore water profiles similar to those observed in coastal sediments. Sulfate reduction is accompanied by the production of large concentration gradients of alkalinity, phosphate, ammonia and dissolved organic carbon and the formation of large subsurface maxima in Fe and Mn. These profiles demonstrate that bacterially-mediated processes of organic matter degradation and redox reactions are operating in the laboratory experiments.

A vertical profile of ^{55}Fe in pore waters is reported for the first time. This artificial radionuclide follows the profile of stable Fe and as such has a large (200 dpm/100 kg) sub-surface maximum between 2-4 cm depth. Ratios between sediments and pore waters show that there is preferential chemical reduction and solubilization of ^{55}Fe over stable Fe. Iron-55 may be a better indicator of Fe biogeochemistry than stable Fe.

The pore water concentrations of ^{239,240}Pu range between 0.13 and 0.23 dmp/100 kg and show no gradients within the large uncertainties of the counting statistics. These Pu concentrations, however, are significantly higher than the water overlying the sediments in the experimental tank (0.11 dpm/100 kg) and than Buzzards Bay seawater (0.05 dpm/100 kg). The higher pore water concentrations may result from an equilibrium with solid phase Pu and/or diagenetic reactions: at present, the data cannot distinguish between the two.

The concentration of ^{137}Cs in the pore water profile and overlying water is constant (40 dpm/100 kg) within the large counting uncertainties and is twice that of Buzzards Bay seawater. Cs-137 does not appear to be involved in diagenetic chemistry but may increase in pore waters as a result of ion-exchange.

Fluxes calculated from the pore water data show that (1) the remobilization and transport of ^{239,240}Pu is not a significant process in coastal sediments and (2) ^{137}Cs transport may be of potential significance.

THE MAJOR-ELEMENT CHEMISTRY OF SUSPENDED PARTICLES IN THE NORTH BASIN OF WINDERMERE

Edward R. Sholkovitz and David Copland

Detailed vertical profiles were taken in the north basin of lake Windermere between July and November 1980. Measurements were made of temperature, dissolved oxygen, pH, total suspended load and the major-element composition (organic C, Al, Fe, Mn, Si, S, P, Ca, Mg, Ba and K) of suspended particles.

Excess concentrations (those reactive phases not supported by detrital phases) of particulate S, P, Ca, Mg, Ba and K are highest in the epilimnion due to their incorporation into the growing phytoplankton. These elements are associated with planktonic organic matter and are rapidly recycled in the upper 25 m of this 60 m oxic lake. This is documented by the decrease with depth of both excess concentrations of S, P, Ca, Mg, Ba and K and their ratios to POC. Large concentrations of excess particulate Si occur during the spring bloom. These siliceous particles do not contain significant quantities of excess particulate S, P, Ca, Mg, Ba and K. This observation supports the conclusion that organic matter is the important recycling matrix for these inorganic elements.

Elevated concentrations of excess particulate Mn at depth indicate that there is a Mn-redox cycle operating in the lake.

DEPARTMENT OF GEOLOGY AND GEOPHYSICS

Richard P. von Herzen, Department Chairman

GEOLOGY and GEOPHYSICS

G E O L O G Y

EIGENANALYSIS OF RECENT
UNITED STATES SEA LEVELS

David G. Aubrey and Kenneth O. Emery

Spatial and temporal patterns of recent sea-level rise along the U.S. coastline have been examined to ascertain rates of rise, and possible causes for high-frequency fluctuations in sea level. Eigenanalysis identified several distinct coastal compartments within each of which sea-level behavior is consistent. The U.S. east coast has three of these compartments: one north of Cape Cod, where sea-level rise increases with distance to the north; one between Cape Cod and Cape Hatteras where sea-level rise increases to the south; and the third from Cape Hatteras south to Pensacola, where sea-level rise decreases to the south. The western Gulf coast represents another compartment (poorly sampled in this study), where subsidence is partly due to compaction. The final compartment is along the U.S. west coast, where poor spatial sampling produces a highly spatially variable sea-level record that has some temporal uniformity. Spectral analysis shows a dominant time scale of six years for sea level variability, with different coastal compartments responding relatively in or out of phase. No evidence for increased rates of sea-level rise over the past ten years was found. This objective statistical technique is a valuable tool for identifying spatial and temporal sea level trends in the United States. It may later prove useful for identifying elusive world-wide trends of sea level, related to glacial melting, glacial rebound, tectonism, and volcanic activity.

RAPID FORMATION AND DEGRADATION
OF BARRIER SPITS IN AREAS
WITH LOW RATES OF LITTORAL DRIFT

D.G. Aubrey and A.G. Gaines, Jr.

A small barrier beach exposed to low energy waves and a small tidal range (0.7 m) along Nantucket Sound, MA, has experienced a remarkable growth phase followed by rapid attrition during the past century. In a region of low longshore transport rates, the barrier spit elongated approximately 1.5 km from 1844 to 1954, developing beyond the baymouth, parallel to the adjacent Nantucket Sound coast. Degradation of the barrier spit was initiated by a succession of hurricanes in 1954 (Carol, Edna and Hazel). A breach opened and stabilized near the bay end of the one-kilometer long inlet channel, providing direct access for exchange of bay water with Nantucket Sound, and separating the barrier beach into two nearly equal limbs. The disconnected northeast limb migrated shorewards, beginning near the 1954 inlet and progressing northeastward, filling the relict inlet channel behind it. At present, about ten percent of the northeast limb is subaerial: the rest of the limb has completely filled the former channel and disappeared. The southwest limb of the barrier beach has migrated shoreward, but otherwise has not changed significantly since the breach.

A new mechanism is proposed for spit elongation when the inlet thalweg parallels the beach axis, in which material scoured from the lengthening inlet is the dominant source for spit accretion (perhaps initially deposited as a linear channel-margin bar which later becomes subaerial). The lengthening spit causes the parallel inlet to elongate, which in turn further lengthens the spit, in a self-generating fashion. This mechanism provides both a source of sediment for elongating the barrier spit, and a sink for material scoured from the lengthening inlet. The proposed mechanism for spit growth may be applicable to other locations with low wave energy, small tidal prisms, and low longshore sand transport rates, suggesting that estimates of directions and rates of longshore sand transport based on spit geomorphology and development be scrutinized on a case-by-case basis.

RECENT EVOLUTION OF AN ACTIVE BARRIER
BEACH COMPLEX: POPPONESSET BEACH,
CAPE COD, MASSACHUSETTS

David G. Aubrey and Arthur G. Gaines, Jr.

1. Popponesset Spit and beach features near the mouth of Cotuit Bay have experienced active changes over the past two centuries. These changes have included growth and attrition of Popponesset Spit as

well as its landward migration, loss of a small island near Cotuit Bay, and opening and closing of breachways.

2. The length of Popponesset Spit has changed nearly 1.5 km (0.93 miles) during the past century, including a) a growth phase from about 1850 to 1954, and b) an attrition phase following 1954.

3. While neither growth nor attrition appear to have resulted from human activities, the exact causes remain conjectural. Growth of the spit appears to have been closely associated with lengthening of the inlet, by means of a process by which material removed from the inlet became deposited on the end of the spit. Attrition (which affected the northeast limb only) appears to be associated with a process of landward sand movement following the breach event in 1954, eliminating most of the barrier beach and the inlet channel immediately behind it.

4. The Southwest limb, Popponesset Spit as it exists at present, has not experienced appreciable net change in length since 1954.

5. Landward migration of Popponesset Spit has amounted to about 55 to 140 meters (60 to 153 yards) since 1938 (1.3 to 3.5 m/yr or 4.3 to 11.5 ft/yr) accompanied by a slight counterclockwise rotation of its orientation. The migration includes a long term trend as well as conspicuous displacements associated with major storms.

6. Despite this migration, the average width of Popponesset Spit has not changed dramatically, judging from historical maps and photos.

7. Breaches in the spit over the past 200 years have occurred principally near Popponesset Island, Little Thatch Island and west of Big Thatch Island. Since 1961 overwash events have occurred at these sites but stable inlets have not resulted.

8. Because of dredging in the bay and land-ward migration of the beach, the Popponesset Island site appears increasingly prone to breaching. A breach at this site may become a permanent inlet and result in numerous management consequences.

9. Longshore drift could not be estimated accurately, but appears from more than one line of evidence to be less than previous studies imply. Cliff retreat Southwest of Popponesset, which is too small to resolve with the methods used in this study, is therefore less than about 0.23 m/yr (0.75 ft/yr). This could supply a maximum of about 3,000 m^3/yr (4,000 cubic yards) to the beach, of which an unknown portion would be delivered to Popponesset Spit. The actual amount could also be much less.

10. The direction of net littoral drift as suggested by several geomorphological indicators probably involves convergence toward the mouth of Cotuit Bay. Seasonal variations in longshore transport direction are evident.

Rb-Sr GLAUCONITE ISOCHRON OF THE EOCENE CASTLE HAYNE LIMESTONE, NORTH CAROLINA - FURTHER DISCUSSION

W.A. Berggren and M.-P. Aubry

The 11-meter thick lectostratotype of the Castle Hayne Limestone Formation selected by Baum et al. (1978) in New Hanover County, North Carolina (Fig. 1; also see Ward et al., 1978), has become the subject of considerable interest in recent times because of a reported Rb-Sr glauconite isochron date of 34.8 Ma±1 Ma (Harris, 1979; Harris and Zullo, 1980; Fullager et al., 1980) at a stratigraphic level (Fig. 2) interpreted as belonging to calcareous nannoplankton zones NP19 and NP20 (= late Eocene, Priabonian Stage; Turco et al., 1979; Worsley and Turco, 1979). Different age interpretations based upon other biostratigraphic evidence were reviewed by Harris and Zullo (1980) but the authors opted for a late Eocene age based on the calcareous nannoplankton evidence. In a critique of the above studies Jones (1982) has presented evidence from planktonic foraminifera suggesting that the Castle Hayne Formation is of Zone P11-12 age (middle Eocene, Lutetian Stage), while, in a reply, Harris and Zullo (1982) defend and retain their late Eocene age interpretation.

Accurate radiometric dates are important both as calibration points and consistency checks in the formulation of geological time-scales. Of paramount importance is precise biostratigraphic control on radiometrically dated levels so that they may serve as internal consistency checks upon each other as additional data are compiled over the years. In recent years there have developed two "schools" of thought regarding the age of the Eocene/Oligocene boundary, a so-called orthodox school (Berggren, 1972; Hardenbol and Berggren, 1978) who believe that the boundary has an age of about 37 Ma; a vocal minority (Odin, 1978; Odin et al., 1978; Glass and Zwart, 1977; Harris and Zullo, 1980, 1982) believe the boundary is considerably younger, ca. 33-34 Ma. A third group has taken an intermediate position with age estimates in the 34-35 Ma range.

Because of the controversy surrounding Paleogene chronology in general, and the Eocene/Oligocene boundary in particular, we have decided to make a comment on this particular study and, what we view, as some anomalous results. In order to treat the problem in its proper perspective it is necessary to bring in data from a variety of fields and to range over a spectrum of Paleogene stratigraphy. However, we shall try to confine the discussion, as much as possible, to middle Eocene and upper Eocene stratigraphy. A comprehensive review of Paleogene bio- and chronostratigraphy, and magneto- and radiochronology, and a thoroughly revised Paleogene time scale is being prepared by W.A. Berggren, Dennis Kent and John T. Flynn. In this paper we shall demonstrate that the Castle Hayne Formation:

1) is of late Middle Eocene (late Lutetian to early Bartonian) age,

2) is no older than planktonic foraminiferal zone P12, nor younger than P14, and is most likely correlative with upper Zone P12 to Zone P13,

3) belongs to calcareous nannoplankton Zones NP16 (upper part) to NP17 (lower part),

4) at a maximum spans the interval represented by magnetic polarities 20 to 18 (= 46-42 Ma, LaBrecque et al., 1977; = 45-41 Ma, Ness et al., 1980), at a minimum spans the interval bracketing the base of anomaly 18 (= 43-42.5; LaBrecque et al., 1977; = 42-41.5 Ma, Ness et al., 1980).

Further, we shall show that available data now support an age of 36.5-37 Ma for the Eocene/Oligocene boundary.

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DEEP CIRCULATION OF THE NORTH ATLANTIC OVER THE LAST 200,000 YEARS: GEOCHEMICAL EVIDENCE

E.A. Boyle and L.D. Keigwin, Jr.

Variations in the Cd:Ca ratio of North Atlantic Deep Water are recorded in the fossil shells of benthic foraminifera. The oceanic distribution of cadmium is similar to that of the nutrients, hence Cd:Ca in shells proxy for temporal variations in nutrient distributions. Data from a North Atlantic sediment core show that over the past 150,000 years there has always been a continuous supply of nutrient depleted waters into the deep North Atlantic. The intensity of this source relative to nutrient enriched southern waters diminished by a factor of two during severe glaciations. This evidence is combined with $\delta^{13}C$ data to argue that the continental carbon inventory has been less variable than previously suggested.

OLIGOCENE CALIBRATION OF THE MAGNETIC POLARITY TIMESCALE

Donald R. Prothero, Charles R. Denham and Harlow G. Farmer

Magnetostratigraphic studies of the Oligocene White River Group in Wyoming, Colorado, Nebraska, and the Dakotas yield a radiometrically dated polarity stratigraphy that provides mid-Tertiary calibration points for the magnetic polarity time scale. Anomaly 12-13 reversal is bracketed by dates of 32.4 and 34.6 my, in best agreement with the time scale of LaBrecque and colleagues. The magnetostratigraphy also helps calibrate the Oligocene North American land mammal "ages" and allows correlation with the European marine microfossil zonation. This correlation suggests that the age of the Eocene-Oligocene boundary is 37.0 my, contrary to younger dates obtained from glauconites and microtektites.

ISOTOPIC PALEOCEANOGRAPHY OF THE CARIBBEAN AND EAST PACIFIC: ROLE OF PANAMA UPLIFT IN LATE NEOGENE TIME

Lloyd D. Keigwin, Jr.

Comparisons of carbon isotopic data on benthic foraminifera from Deep Sea Drilling Project sites 502 (western Caribbean) and 503 (eastern Pacific) indicate that the difference between the Atlantic and the Pacific in the per mil enrichment in carbon-13 of total dissolved carbon dioxide increased about 6 million years ago and

again 3 million years ago, when the difference reached the modern level (1 per mil). Comparisons of planktonic foraminiferal oxygen isotopic data for the Caribbean and the Pacific suggest that the salinity of Caribbean surface waters began increasing 4 million years ago, possibly in response to shoaling of the Panama isthmus. These results suggest that modern circulation patterns in the Caribbean and eastern Pacific developed by 3 million years ago in concert with changing tectonic, climatic, and biogeographic patterns.

STABLE ISOTOPIC EVIDENCE FOR LATEST MIOCENE SEA-LEVEL FALL IN THE MEDITERRANEAN REGION

T.S. Loutit and L.D. Keigwin, Jr.

The discovery of a marked isochronous decrease of carbon isotope ratio values (0.5-0.8°/$^\circ$ in marine carbonates at about 6.2 Ma has stimulated a number of speculations regarding the origin of this event, including: (1) increased vital effects in response to increased fertility; (2) increased basin-to-basin fractionation due to increased production of North Atlantic deep waters, with higher AOU (apparent oxygen utilization) in Indo-Pacific bottom waters; and (3) increased supply and oxidation of organic matter. Climatic and oceanographic events that may be closely associated in time with the decrease in $\delta^{13}C$ values include: (1) an overall cooling of surface water; (2) an increase in bottom water circulation rates and fertility of the oceans; (3) lowering of sea level; (4) the isolation and drying up of the Mediterranean; (5) the shoaling of the Isthmus of Panama; (6) an increase in biogenic silica removal in the Southern Ocean high productivity zone; (7) a decrease in biogenic silica sedimentation in the eastern equatorial Pacific; (8) a change over from an Atlantic CCD shallower than the Pacific CCD before the shift to a deeper CCD in the Atlantic after the shift; and (9) an increase in deep-sea accumulation rates. No satisfactory explanation has yet been provided for the cause of the decrease in $\delta^{13}C$ values and its apparent close temporal association with these other paleoceanographic phenomena.

ABUNDANCE PROFILES OF IRIDIUM AND OTHER ELEMENTS NEAR THE CRETACEOUS-TERTIARY BOUNDARY IN HOLE 516F

H.V. Michel, F. Asaro, W. Alvarez, L.W. Alvarez and D. Johnson

Anomalously high values of Ir have been detected in association with the Cretaceous-Tertiary (K-T) boundary in about a dozen marine or continental sections laid down some 65 my ago in many different parts of the world (Alvarez et al., 1981). One possible exception is the K-T boundary region in DSDP Leg 39 Hole 356 in the South Atlantic off the coast of South America, where the maximum Ir abundance was about 0.2 ppb, much lower than 3-90 ppb found in most of the other marine locations (Michel et al., 1982a, unpublished data). A study of Site 516F, which is relatively near Site 356, is of particular interest as it could show whether the very low (or missing) C-T Ir anomaly at Site 356 is characteristic of this region of the South Atlantic. Results from Site 516F show a maximum in Ir of 0.95±0.18 ppb in core 89-5, 33.0-33.5 cm; total Ir in the interval around this maximum is 12 nanograms/cm^2. Thus this region of the Atlantic does demonstrate an anomaly in Ir at the K-T boundary.

LATE PALEOGENE (EOCENE TO OLIGOCENE) BENTHIC FORAMINIFERAL PALEOCEANOGRAPHY OF THE GOBAN SPUR REGION, DSDP LEG 80

Kenneth G. Miller, William B. Curry and Dorinda R. Ostermann

Major benthic foraminiferal changes occur in the late Eocene of Site 549; a Nuttallides truempyi-dominated assemblage is replaced by a buliminid assemblage (~ 38.5-40 Ma). This assemblage is replaced, in turn, by an assemblage dominated by stratigraphically long-ranging and bathymetrically wide ranging taxa just below the Eocene/Oligocene boundary (~ 37.5 Ma). A series of late Eocene to earliest Oligocene first and last appearances accompany these abundance changes. Similar faunal abundance changes occur at Site 548;

however, the incomplete record recovered at Site 548 prevents a firm dating of the changes. No major benthic foraminiferal changes are associated with the Eocene/Oligocene boundary (denoted by the extinction of Hantkenina, Cribrohantkenina, and Globoratalia cerroazulensis); instead, benthic foraminiferal abundance changes, extinctions, and first appearances occur throughout the late Eocene to earliest Oligocene interval (~ 36-40 Ma).

$\delta^{18}O$ increases ~ 1.0 ^{o}/oo in the late Eocene to earliest Oligocene at Site 549. The bulk (~ 0.7^o/oo) of this increase occurs together with a 0.6^o/oo increase in $\delta^{13}C$ as a geologically rapid event in the earliest Oligocene. The $\delta^{13}C$ record at Site 549 shows a late Eocene increase that correlates with a decrease in abundance of N. truempyi. The earliest Oligocene isotopic enrichments (~ 36.5 Ma) correlate with a prominent seismic horizon, reflector R4, noted in the Labrador Sea and Rockall regions. This horizon represents increased intensity of abyssal circulation. Late Eocene faunal and isotopic changes that pre-date the seismic stratigraphic event are thought to reflect a series of hydrographic changes representing the first influence of Arctic and/or Norwegian-Greenland Sea water on the deep North Atlantic. These changes culminated in a temperature drop, decrease in the age of bottom water, and an increase in intensity of circulation associated with reflector R4 near the Eocene/Oligocene boundary.

WORLD-WIDE DELIVERY OF RIVER SEDIMENT TO THE OCEANS

J.D. Milliman and R.H. Meade

New data and new estimates from old data show that rivers with large sediment loads (annual discharges greater than about 15×10^6 tons) contribute about 7×10^9 tons of suspended sediment to the ocean yearly. This value varies from previous estimates in part because of the trapping of sediment in many rivers by recently-completed dams. Extrapolating available data for all drainage basins, the total suspended sediment delivered by all rivers to the oceans is 13.4×10^9 tons annually; bedload and flood discharges may account for an additional $1-2 \times 10^9$

tons. About 70 percent of this total is derived from southern Asia and the larger islands in the Pacific and Indian Oceans, where sediment yields are far greater than for other drainage basins.

THE SHELFBREAK: SOME LEGAL ASPECTS

David A. Ross and K.O. Emery

Conferences on Law of the Sea have had the objective of increasing the area of ocean floor subject to control by adjacent coastal countries. These extensions of jurisdiction have paid little attention to carefully defined and relatively easily identified geological boundaries. Indeed often a geological term is used in a legal sense, that far exceeds the geological meaning, resulting in unnecessary confusion. The recently concluded Third United Nations Conference on the Law of the Sea adds an area of the ocean subject to national control equal to that of the land area of the world. Certain aspects of the remaining area of deep-ocean floor, such as mining, will also be controlled and taxed by an international authority. It is possible future oceanographers may have little opportunity for research without permission and regulation by governments of either coastal nations or the United Nations. One result could be increased research and knowledge of the ocean floor that is under the jurisdiction of industrialized countries and decreased effort in the rest of the ocean.

HISTORICAL DEVELOPMENT AND TIDE PREDICTION USING THOUSAND-YEAR-OLD TIDE TABLES

Yang Zuo Sheng, K.O. Emery and Xui Yui

Tide-prediction tables require an understanding of relation of tide to moon and sun, as expressed by the correspondence of maximum tide heights to phases of the moon and the lag of high tide after local meridional transit of the moon. These relations were published earlier in the Middle East-Europe region than in China,

doubtlessly because of novelty of tides to travelers from the nearly tideless Mediterranean Sea. However, tide-prediction tables were compiled earlier in China than elsewhere--more to satisfy the interests of sightseers of spectacular river bores than for convenience of shipping. The earliest extant Chinese tables (of +1056) were used to plot the bore near Hangzhou (old Hankow) for comparison with predictions from modern tide tables. The fit of hour and height is excellent for the ten days or so of highest (perigeean) tides, but the ancient tables do not select the higher of the two daily apogeean high tides during much of the rest of the month. Spectators were more interested in highest bores produced by periggean tides, anyway.

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BEACH CHANGES AT NAUSET INLET, CAPE COD, MASSACHUSETTS 1670-1981

P.E. Speer, D.G. Aubrey and E. Ruder

An historical study of barrier beach and inlet changes for the Nauset Inlet region, Cape Cod, Massachusetts, was performed to document patterns of beach and inlet change as a preliminary to designing and carrying out field studies of inlet sediment transport. One hundred-twenty historical charts from 1670 and 125 sets of aerial photographs from 1938 formed the basis for this study. Specific aspects of barrier beach and inlet change addressed include onshore barrier beach movement, longshore tidal inlet migration, and longshore sand bypassing past the inlet. In an effort to correlate forcing events with barrier changes, an exhaustive study of the local storm climate was performed. Detailed treatment of the specific mechanisms responsible for Nauset Inlet migration episodes in a direction opposite the dominant littoral drift are treated in a companion paper by Aubrey, Speer, and Ruder (1982). Documentation of the data base available for the Nauset area is presented herein as appendices.

STRUCTURE AND ORIGIN OF THE J-ANOMALY RIDGE, WESTERN NORTH ATLANTIC

Brian E. Tucholke and William J. Ludwig

The J-Anomaly Ridge (JAR) is a structural ridge or step in oceanic basement that extends southwest from the eastern end of the Grand Banks beneath the "J" magnetic anomaly at the young (M-4 to M-0) end of the M-series magnetic anomalies. Its structural counterpart beneath the "J" anomaly in the eastern Atlantic is the Madeira-Tore Rise (MTR), but this feature has been over-printed by post-middle Cretaceous deformation and volcanism. In order to study the origin and evolution of the JAR-MTR system, we obtained seismic refraction and multi-channel reflection profiles across the J-Anomaly Ridge near 39°N latitude. These data show that the western ridge flank consists of a series of crustal blocks downdropped along west-dipping normal faults, but the eastern slope into younger crust is gentle and relatively unfaulted. The western flank is subparallel to seafloor isochrons, becoming younger to the south. Anomalously smooth basement caps the ridge crest, and it locally exhibits internal, seaward-dipping reflectors similar in configuration to those within subaerially emplaced basalt flows units on Iceland. Isostatically corrected for sediment load, the northern part of the J-Anomaly Ridge has basement depths about 1400 m shallower than in our study area, and it is known from deep-sea drilling to have been subaerially exposed during the middle Cretaceous. We suggest that most of the JAR-MTR system originated under subaerial conditions at the time of late-stage rifting between the adjacent Grand Banks and Iberia. The excess magma required to form the ridge probably was vented from a mantle plume beneath the Grand Banks-Iberia rift zone, and channeled southward beneath the rift axis of the abutting Mid-Atlantic Ridge. Resulting edifice-building volcanism constructed the ridge system between anomalies M-4 and M-0, propagating southward at about 5 cm/yr. At the time that true drift began between Iberia and the Grand Banks (about M-0 time), this southward venting rapidly declined. The results were rapid return of the spreading axis to normal elevations, division of the ridge system into the separate J-Anomaly Ridge and Madeira-Tore Rise, and unusually fast subsidence of at least parts of these ridges to depths that presently are near normal. The proposed origin and evolutionary sequence for the JAR-MTR system closely matches events of uplift and unconformity development on the adjacent Grand Banks.

THE WESTERN NORTH ATLANTIC:
PERSPECTIVES ON GEOLOGICAL SYNTHESIS

P.R. Vogt and B.E. Tucholke

We have devised the following format
and philosophy for the Decade of North
American Geology volume on the western
North Atlantic basin. The basic simplicity
of the crustal section allows us to divide
the book subequally into an "igneous-
tectonic" part and a "sediment-
paleoceanography" part. The "igneous-
tectonic" part will introduce the volume
because these processes have influenced
sediment distribution and paleoenvironment,
rather than vice versa. About 15 percent
of the text is devoted to an introduction
and to synthesis/perspectives, as well as
to several important but miscellaneous
topics that do not fit easily elsewhere.
Three of these topics (History of
Geological Exploration, Bathymetry, and the
Geomagnetic Time Scale) follow our
Introduction. Three others (Resources;
Engineering Properties and Hazards; Law of
the Sea) precede the Conclusion.

The philosophy adopted here is that our
DNAG volume should be a concise summary,
useful to both continental and marine
geologists, of the "known" and
"problematic" geologic framework of the
western Atlantic. The "known" geology will
be summarized largely from the major
advances of the past 20 years and how they
have modified earlier thinking. The
unknown or "problematic" geology can be
divided into: 1) clear definition of major
problems that cannot at this time be
resolved but for which research plans can
be prepared; 2) resolution of some
currently perceived problems via the
present synthesis vehicle. The latter
supposes, as is usually true, that the
"whole is greater than the sum of the
parts", but the success of this effort will
be highly dependent upon our insight to
recognize important problems and coordinate
efforts of individual authors to resolve
them.

GEOPHYSICS

DEPTH OF PRINCIPAL MASS ANOMALIES IN
CONTRIBUTING TO THE EARTH'S GEOIDAL
UNDULATIONS AND GRAVITY ANOMALIES

Carl Bowin

To help decipher the distribution of
the principal mass anomalies within the
earth, an analysis is made of the earth's
potential field by simultaneously
considering both gravity and geoid
anomalies. Ancillary knowledge about the
earth from astronomical, angular momentum,
seismological, and plate tectonic studies
aids in deciding between deep or broad
shallow mass anomalies as the causative
source of certain potential field anomalies.

The geoid (or gravity) anomaly for an
individual gravity potential field feature
as a function of increasing spatial
resolution (decreasig wavelength) is
obtained by stepwise accumulating the
contributions of spherical harmonic
coefficients for each degree and order for
any selected location. This is equivalent
to displaying the spectral content of an
anomaly. The ratio of gravity to geoid
(g/N) for each individual harmonic degree
is independent of the harmonic coefficient
values, being determined only by the degree
and values for normal gravity and the
earth's radius. This g/N ratio value has
an equivalent point mass depth. Thus, the
gravity and geoid contributions from each
individual degree have a fixed ratio value
in proportion to that of point masses at a
depth of some fraction of the earth's
radius, and this depth places a greater
constraint on the depth of the source mass
anomaly than can be obtained from
wavelength considerations. Curves are
presented that quantify the g/N relations
for two simple geometric bodies. Mass
anomalies that may exist in the earth at
great depth will be best represented in the
coefficients of the low degree spherical
harmonics, not only because of their longer
wavelength anomalies at the surface, but
also to match better the resulting ratio of
gravity to geoid values. Shallow (less
than 350 km) broad sources that might be
considered possible sources of the degree
2* and 3* contributions of the Sri Lanka
geoid low and New Guinea geoid high are
shown to be implausible, whereas 1 to 2 km

of relief on the core mantle boundary can explain the combined degree 2 and 3 geoid and gravity anomalies.

A preliminary decomposition of the earth's gravity field is made using these new considerations. This decomposition comprises four main sources for mass anomalies: 1) mass anomalies at the core-mantle boundary region expressed principally in coefficients of harmonic degrees 2* and 3*, 2) mantle anomalies, and the mass excess of the deeper portions of plate convergent zones, expressed principally in coefficients of harmonic degrees 4* through 10*, 3) upper mantle mass anomalies in the outer 600 km of the earth revealed by residual geoid anomalies from radar altimeter observations, and 4) crustal anomalies revealed by residual free-air gravity anomalies. The observational data cited do not perfectly distinguish between these four sources of mass anomalies, as well as between other possible lesser contributors. However, the evidence is sufficiently reasonable to give credence to the decomposition. The degree 10 geoid thus provides an estimate of the combined contributions from mass anomalies at the core-mantle boundary region and from the deep mantle and deeper parts of plate convergent zones. Its subtraction from radar altimeter data indicates mass anomalies in the outer 600 km, which in turn provides new information regarding the nature of convection within the upper mantle.

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FREE-AIR GRAVITY ANOMALY MAP AND ATLAS OF THE WORLD

Carl Bowin, Waris Warsi and Julie Milligan

A free-air gravity anomaly and atlas of the world has been completed. Contour interval for both map and atlas is 25 mgal. The free-air gravity anomaly contours have been either hand-contoured from digital data (from a library of over 3,600,000 measurements) or incorporated from published maps. The gravity anomaly values are referenced to the internation of gravity formula with IGF 1967 with a reference ellipsoid having a flattening of 1/298.247. The atlas (Geological Society of America Map and Chart Series No. MC-46) comprises two sheets for polar regions and 84 sheets at mercator projection on a scale of 1:8,000,000. The atlas sheets were reduced and assembled to construct a world gravity map in color at a scale of 1:21,333,333 (GSA Map and Chart Series No. MC-45).

The most striking anomalies are those associated with the island arc/trench structures. Linear parallel belts of strong negative and positive gravity anomalies encircle all but the southernmost part of the Pacific Ocean basin. The gravity anomaly pattern of the Indonesian arc system links to the southern front of the Himalaya plate convergent zone near longitude 95°E. Westward from this junction, a zone of large positive and negative free-air gravity anomalies continues to the eastern Atlantic Ocean basin. This zone coincides with the Tethys, a Permian to early Tertiary sea along the general course of the Alpine-Himalayan orogenic belt. The zone has a complicated pattern in detail, and important negative anomalies flank both its northern and southern edges. At a few locations the edges pinch together and coalesce, such as between southernmost Italy and Greece and in Afghanistan centered at about 37°N latitude and 72°E longitude. The very large negative anomalies (-300 mgal) in Afghanistan occur where the terrain is typically over 1 km above sea level. Anomalies even near zero mgal are unusual for elevated terrain; thus, the large negative values in Afghanistan are indeed striking. From this compilation it can be seen that the mass deficiency that exists there exceeds that of any other mass anomaly in the crust of the earth.

Perhaps the next most notable aspect of the compilation is the fact that continental areas do not clearly stand out from oceanic regions except where a convergent plate boundary coincides with their juxtaposition. For example the edges of Africa, Europe, and North and South America are difficult to discern in the Atlantic region. Small anomalies do typically occur at the shelf edge of continents, but other anomaly patterns obscure the continental edges over broad regions. The inverse relation between anomaly size and the dimension of corresponding features indicates that the earth's crust is generally in isostatic equilibrium. The patterns of anomalies seen in the world map and atlas are inferred to be predominantly (about 90 percent) in response to crustal and mantle anomalies in the outer 600 km of the earth.

Published in: Geological Society of America Map and Chart Series, MC-45 and MC-46.

FOURIER DOWNWARD CONTINUATION OF ECHOSOUNDINGS

Charles R. Denham

A two-dimensional re-creation of
seabottom topography can be obtained
through underway Fourier processing of
echosoundings aboardship. This corrective
procedure restores sloping reflectors and
collapses diffractions virtually in
realtime, by simple phaseshift operations,
utilizing the Fourier domain as the primary
data storage and working space. An
application to some actual deepwater 3.5
kHz echosounding data shows that the
restorative power of the processing depends
directly on the continuity of the acoustic
features. The illustrative data are a 30-km
profile over abyssal hills in the North
Pacific.

UNCONSOLIDATED SEDIMENTS AND SHALLOW STRUCTURE OF THE NORTHERN BARENTS SEA

Y. Kristoffersen, J.D. Milliman
and J.P. Ellis

The northern Barents Sea is dominated
by NE-SW trending ridges and intervening
basins. Except for moraine/till deposits
on the bank area at 77°30'N, 34°E and piles
of acoustically transparent sediment
seaward of the melting glaciers on southern
Nordaustlandet, generally less than 10-15
meters of unconsolidated sediment occurs on
the ridges and in shallow water areas.
Basins locally contain more than 40 m of
unconsolidated sediment. Only the top
meter of this unit appears to be modern.
The rest was glacially deposited during the
late Weichselian.

Seismic profiles show southward dipping
rocks south of the Nordaustlandet-Kvitøya
high. Correlation with land geology and
dredged rocks suggests the strata to be
Permo-Carboniferous cherts and sandstones.
The eastern part of King Karls Land is
along the axis of a syncline trending along
the island chain which marks the transition
to structurally more complex strata to the
south. Presumably the more complex
structure represents more intensive
regional deformation, possibly induced by
salt movement or block faulting at depth.

THE SEISMIC STRUCTURE OF 140 MY OLD CRUST IN THE WESTERN CENTRAL ATLANTIC OCEAN

G.M. Purdy

A detailed seismic refraction experi-
ment using explosive sources and ocean
bottom hydrophone (OBH) receivers was
carried out over Mesozoic magnetic anomaly
M17 about 300 km south west of Bermuda.
Amplitude and travel time interpretations
show this 140 my old crust to be uniform,
on the seismic scale, over a lateral
distance of almost 100 km. The best esti-
mate of the velocity structure consists of
an average 700 m of sediment overlying a
total thickness of igneous crust of 7.2
km. The principle components, beginning
with a 5km/s velocity at the top of layer
2, are a 0.4 km thickness with gradient
$1.1s^{-1}$, a 1.9 km thickness with gradient
$0.64s^{-1}$, 1.7 km thickness with gradient
$0.1s^{-1}$, a 3.2 km thickness with zero
gradient and constant velocity of 7km/s
below which lies 0.5 km thick moho
transition zone. The uppermost few
kilometers of the upper mantle apparently
has little or no velocity gradient. The
normal incidence two way reflection time
through this structure agrees to better
than 0.1s with the location of the moho
reflection seen as the IPOD/USGS
multichannel reflection profile that passes
within 1 km of this experiment. The travel
times of the converted shear wave arrivals
constrain Poisson's ratio in the igneous
crust to ~0.28+0.01. A delay time study of
a 20 km radius circle of shots fired around
a small (~6 km) five element array of ocean
bottom hydrophone receivers confirms the
uniformity of structure of this old crust
on the scale of a few kilometers. The
observed differences in shallow crustal
delay time between the five OBH instruments
can be wholly attributed to differences in
sediment thickness beneath the receivers as
determined by a deep towed hydrophone
seismic reflection profile. These
experiments were located clear of fracture
zones or other structural anomalies in a
region of well defined linear constant
amplitude magnetic anomalies. We propose
that this was the primary cause of our

result of lateral uniformity of structure on the scale of a few kilometers. We suggest that the reason that such a simple uniform structural model for oceanic crust is not supported by the historical seismic refraction dataset is that a large proportion of the old experiments were poorly located with respect to fracture zones and other structural anomalies (unknown at the time) and the data density and sediment thickness information available for each experiment was insufficient to overcome the errors introduced by the basement topography.

REFLECTION PROFILING IN THE DEEP OCEAN USING A NEAR BOTTOM HYDROPHONE

G.M. Purdy and L.A. Gove

A 30 km long high resolution seismic reflection profile was carried out approximately 300 km southwest of Bermuda. The data were collected using a small airgun sound source and a single hydrophone receiver towed ~100 m above the seafloor at a depth of ~5400 m. Comparisons with nearby conventional seismic reflection profiles show the considerable improvement of resolving power provided by this method, particularly of the basement morphology beneath the 700 m thick sediment column. The data were recorded digitally and selected data examples show the enhancement provided by filtering, stacking, source deconvolution and corrections for hydrophone motion. The precise picture of basement topography that results from this data is compared with deep tow bathymetry profiles of the present day Mid-Atlantic Ridge Flanks, and is seen to be remarkably similar.

THERMAL ORIGIN OF THE HAWAIIAN SWELL HEAT-FLOW EVIDENCE AND THERMAL MODELS

R.P. Von Herzen, R.S. Detrick, S.T. Crough, D. Epp and U. Fehn

The lithospheric reheating hypothesis for the origin of the Hawaiian swell has been tested by heat-flow measurements along the swell between Hawaii and Midway. Ninety-five measurements at eight carefully selected sites show that the heat flux on the swell increases systematically from near-normal values (52 ± 2 mWm^{-2}) near Hawaii to values near Midway (59 ± 2 mWm^{-2}) about 20-25°/° higher than normal for lithosphere of that age (110 My). This heat-flow pattern is qualitatively consistent with a deep-seated thermal anomaly created in a lithospheric plate moving across a fixed heat source. Modeling of the heat flow and bathymetry data on the Hawaiian swell strongly suggest that the swell is caused by a rapid heating (beginning <5 Ma) of the lower part (>40-50 km) of normal 90-My-old lithosphere over a relatively broad (500-1000 km) region near Hawaii. This model is also consistent with gravity and geoid anomalies associated with the swell which require a low density region in the lower lithosphere, and with flexure studies of seamounts in the Hawaiian chain which indicate that the rigidity of the lithosphere is not significantly reduced by the reheating.

THE INVERSE PROBLEM OF CONSTRUCTING A GRAVIMETRIC GEOID

Victor Zlotnicki, Barry Parsons and Carl Wunsch

Computation of a single geoidal height from gravity acceleration data formally requires that the latter be known everywhere on the earth. We present a computational procedure based on linear inverse theory for estimating geoidal heights from incomplete sets of data. The same scheme can be used to estimate gravity accelerations from altimetry-derived geoids. The systematic error owing to lack of data and the choice of a particular inverse operator is described by using resolution functions and their spherical harmonic expansions. An rms value of this error is also estimated by assuming a spectrum for the unknown geoid. The influence of the size of data region, the spacing between data, the filtering applied to the data, and the model weighting function chosen are all quantified in a spherical geometry. The examples presented show that when low degree spherical harmonic coefficients are available - from satellite orbit analysis - a band-passed version of the geoid can be constructed from local gravity data, even with a relatively restricted data set.

M A G N E T O S T R A T I G R A P H Y

MAGNETOSTRATIGRAPHY OF THE WHITE RIVER GROUP AND ITS IMPLICATIONS FOR OLIGOCENE GEOCHRONOLOGY

Donald R. Prothero, Charles R. Denham
and Harlow G. Farmer

Magnetostratigraphic studies of the
Oligocene White River Group in Wyoming,
Colorado, Nebraska, and the Dakotas have
yielded a radiometrically-dated polarity
stratigraphy. They provide a mid-Tertiary
calibration point for the marine magnetic
polarity timescale. An unusually long
interval of reversed polarity in the
Flagstaff Rim section, Natrona County,
Wyoming, is bracketed by K/Ar dates
(biotite) of 32.4 and 34.6 Ma (corrected
for new decay-constants). It probably
corresponds to the long reversed interval
between marine magnetic anomalies 12 and
13. Also, the magnetostratigraphies of 21
other fossiliferous sections of Chadronian-
Whitneyan (Oligocene) rocks have been
correlated with anomalies 9-12. On this
basis, the "boundaries" of the Oligocene
North American land mammal "ages" are:
Chadronian- Orellan -- mid-anomaly 11-12
reversal (about 32.4 Ma); Orellan-Whitneyan
-- mid-anomaly 10-11 reversal (about 30.7
Ma); Whitneyan-Arikareean -- base anomaly 9
(about 29.0 Ma). These dates are in good
agreement with recent estimates based on
mammalian biochronology and with a
corrected radiometric date of 28.7 ± 0.7 Ma
at the base of the Arikareean.

P A L E O C E A N O G R A P H Y

THE FORAMINIFERAL ISOTOPIC RECORD ACROSS THE EOCENE/OLIGOCENE BOUNDARY AT SITE 540

Paul E. Belanger and R.K. Matthews

We analyzed the oxygen and carbon
isotopic composition of planktonic and
benthic foraminifera picked from thirteen
late Eocene to late Oligocene samples of
DSDP Site 540 (23°49.73'N, 84°22.25'W,
2926 m water depth) from the Gulf of
Mexico. An enrichment occurs in ^{18}O of
about 0.5 to 0.8 $^O/oo$ in both benthic
foraminifera and surface dwelling
planktonic foraminifera between the latest
Eocene and early Oligocene. This early
Oligocene maximum is followed by lower
^{18}O values.

A 1.2 $^O/oo$ $\delta^{13}C$ decrease in both
benthic and planktonic foraminiferal data
occurs from the late Eocene to the late
Oligocene. There is a correspondence of
the ^{13}C signal to deep-sea records;
however, the amplitude of this change is
greater than previously seen in deep-sea
cores, possibly as a result of proximity to
terrestrial sources of carbon.

The covarying isotopic changes in both
benthic and planktonic foraminifera suggest
global causes, such as ice volume increases
and increased terrestrial carbon input to
the ocean. However, during the latter part
of the record (early-late Oligocene), the
increases in the benthic ^{18}O without
accompanying increases observed with
planktonic foraminifera suggest that
changes in only one part of the system
occurred; one potential explanation being a
decrease in bottom water temperatures
without concomitant changes in the surface
waters. The ^{18}O differences between
species of planktonic foraminifera, and the
difference between planktonic and benthic
^{18}O data indicates that diagenesis
problems are minimal. These preliminary
results are encouraging, in light of the
fact that these cores are partially
lithified.

LINKAGE OF NORTH ATLANTIC AND SOUTHERN OCEAN DEEP-WATER CIRCULATION DURING GLACIAL INTERVALS

Bruce H. Corliss

The Antarctic Circumpolar Current (ACC) is one of the major current systems in the world ocean, affecting circulation of all of the major ocean basins. The ACC flows eastward around Antarctica from the surface to about 4000 m depth with a transport on the order of 125 Sverdrups. Deep-sea benthonic foraminifera from one piston core (E49-18) from the southeast Indian Ocean sector of the Southern Ocean were analyzed to determine deep water-mass circulation conditions within the ACC during the late Quaternary. I report here that benthonic foraminiferal faunal patterns closely match northern hemisphere ice-volume changes shown by planktonic foraminiferal oxygen isotopic stratigraphy. The glacial-interglacial faunal oscillations are interpreted to reflect the presence of a deep water-mass in the ACC during glacial times which differs from modern Circumpolar Deep Water. I suggest that deep-water circulation changes within the ACC during the interval 440,000 to present are directly linked to changes in North Atlantic Deep Water (NADW) circulation.

CARBONATE SEDIMENTATION BENEATH THE ANTARCTIC CIRCUMPOLAR CURRENT DURING THE LATE QUATERNARY

Bruce H. Corliss and Robert C. Thunell

Calcium carbonate content and planktonic foraminiferal fragmentation have been studied in four late Quaternary Eltanin piston cores (E48-22, E48-28, E49-18, E49-23) taken from the Southeast Indian Ridge between 3200 and 3400 m water depth beneath the Antarctic Circumpolar Current. The calcium carbonate records in the two southernmost cores, E49-18 and E49-23, show distinct glacial-interglacial cycles, with the glacial intervals and intermediate cool intervals having low carbonate values relative to the interglacial times. However, the carbonate records of E48-22 and E48-28 are largely independent of the paleoclimatic records, and may be influenced by input of volcanic ash from the St. Paull or Amsterdam Islands located less than 700 km upwind of the cores.

Planktonic foraminiferal fragmentation, considered to be a dissolution index, indicates that dissolution generally increased during glacial intervals relative to the interglacial intervals in E49-18 and E49-23. In E48-22 and E48-28, the dissolution records do not follow glacial-interglacial patterns, but instead dissolution was greatest during oxygen isotope stage 9, the stages 9/8 boundary, the early part of stage 8, and during stage 7.

No relationship exists between benthonic foraminiferal changes and the fragmentation records in three cores (E48-22, E48-28, E49-23), indicating that deep-water circulation changes had minimal or no influence on these dissolution records. However, in E49-18 the benthonic foraminiferal and the dissolution records are closely matched from oxygen isotope stages 12 to 5 (t = ~440,000 to 120,000 years B.P.). Deep-water circulation changes may have influenced the dissolution record in E49-18, or the two variables may be unrelated, but may have independently responded to glacial-interglacial climatic changes.

PALEOMAGNETICS

DETRITAL REMANENT MAGNETIZATION: VISCOSITY THEORY OF THE LOCK-IN ZONE

Charles R. Denham and Alan D. Chave

Post-depositional remanent magnetization (PDRM) becomes permanent within a lock-in zone, whose apparent time delay (depth) and time span (thickness) are related to the characteristic time constants of compaction and magnetic grain rotation. Two simple models of the PDRM lock-in zone are described, using Yaskawa's idea of effective sedimentary viscosity, and Mooney's empirical relation for the viscosity of a concentrated suspension of spheres. The impulse response of the lock-in zone determines the fidelity of the paleomagnetic recording.

PALEONTOLOGY

BLOW, BLOW, BLOW YOUR HORN

W.A. Berggren

Walter Harry Blow died on April 3, 1972. In a brief, illustrious professional career (spanning but 15 years) he singly (or in collaboration with his colleague Fred Banner) provided us with meticulous morphologic observations and suggested phylogenies of the biostratigraphically important (and numerous less important) Cenozoic planktonic foraminiferal lineages. Nearly all have withstood the test of time in general details. But he was not without his faults and in his paper I trace the pitfalls of making biostratigraphic correlations based on a typologic philosophy of taxonomy and in a framework of "mosaic stratigraphy" which was peculiar (but not exclusive) to Blow. The controversial extension of Planorotalites pseudomenardii into horizons as young as early Eocene (Zone P6) made by Blow (1979) is shown to be incorrect.

It is fitting that we honor his memory by dedicating Symposium 2: Tempo and Mode in Evolution: Micropaleontologic Data, to Walter Blow. Departed now already a decade, Walter is with us in spirit at this occasion. Hail to a giant.

NEOGENE PLANKTONIC FORAMINIFERAL BIOSTRATIGRAPHY AND BIOGEOGRAPHY: ATLANTIC, MEDITERRANEAN AND INDO-PACIFIC REGIONS

W.A. Berggren

A summary is presented of global Neogene planktonic foraminiferal distribution patterns primarily (but not exclusively) based on studies in the first 50 volumes of the Initial Reports of the Deep Sea Drilling Project. The major trends that can be determined include: 1) gradual, predominantly latitudinal provincialization of faunas, with the establishment of a clear cut three-fold faunal subdivision into tropical, temperate and subarctic in the northern hemisphere and a truly Antarctic province in the southern hemisphere by late Miocene time; a truly Arctic province is not seen in the northern hemisphere until the initiation of polar glaciation in mid-Pliocene time (ca. 3 Ma); 2) establishment of disparate faunal distribution patterns in the Pliocene-Pleistocene owing to the elevation of the Isthmus of Panama in mid-Pliocene time; 3) relatively rapid faunal extinction during the late Pliocene, probably linked with dramatic climatic changes.

As a result of these trends in latitudinal biogeographic provincialism a need for multiple biostratigraphic zonation schemes for the purpose of regional (inter- and intra-oceanic) correlation has arisen and a suggested scheme is presented for the Atlantic and Indo-Pacific region.

NEOGENE MAGNETOBIOSTRATIGRAPHY OF DSDP SITE 516 (RIO GRANDE RISE, SOUTH ATLANTIC)

W.A. Berggren, M.-P. Aubry and N. Hamilton

Calcareous plankton biostratigraphy (foraminifera and nannoplankton) and magnetostratigraphy of the upper Oligocene to Pleistocene have been studied in HPC cores 1-44 of IPOD Hole 516, 5-11 of Hole 516A, and 1-11 of Hole 516F, Rio Grande Rise (W.D. 1313m). Some 80 biostratigraphic datum events have been correlated to the magnetic polarity stratigraphy over an interval representing the Matuyama to chron 5, and chrons 16 to 23. Coring disturbance and biostratigraphic evidence of a condensed section precludes unambiguous identification of polarity or biostrati-graphic events over an approximately 30 m interval in the middle and upper Miocene. Sedimentation rates varied considerably during the Neogene but an abnormally thick upper Oligocene and lower Miocene section allows a high degree of magnetobio-chronologic resolution. A new planktonic foraminiferal zonation for the Miocene completes the mid-latitude Neogene zonation of the South Atlantic.

Important magnetobiostratigraphic correlations at Site 516 and their estimated magnetochronology include: 1) Oligocene/Miocene boundary = FAD Globorotalia kugleri = LAD Reticulofenestra bisecta = mid-anomaly 6C (chron 23) = 23.7 Ma; 2) Aquitanian/Burdigalian boundary = LAD Globorotalia kugleri = between base anomaly 6A and top of unnumbered anomaly between 6A and 6B (chron 21) = 21.8 Ma; 3)

Zone N6/N7 boundary = LAD Catapsydrax dissimilis [= FAD Globorotalia pseudomiozea and G. zealandica] = chron 16/17 boundary = 17.6 Ma; 4) Early/Middle Miocene (= Burdigalian/Langhian) boundary = FAD Praeorbulina sicana = mid-part of anomaly 5C (chron 16) = 16.6 Ma or FAD of Praeorbulina suturalis = just above anomaly 5C (inferred) = 16.3 Ma; 5) Zone N8/N9 boundary = FAD Orbulina suturalis above anomaly 5C (later part chron 16, inferred); 6) Miocene/Pliocene boundary = LAD Globoquadrina dehiscens = LAD Globorotalia lenguaensis = basal Gilbert chron = 5.3 Ma.

PALEOGENE GEOCHRONOLOGY AND CHRONOSTRATIGRAPHY

W.A. Berggren, Dennis V. Kent and John J. Flynn

We present a revised Paleogene geochronology based upon a best fit to selected high temperature radiometric dates on a number of identified magnetic polarity chrons (within the late Cretaceous, Paleogene, and Neogene) which minimizes apparent accelerations in seafloor spreading. An assessment of first order correlations of calcareous plankton biostratigraphic datum events to magnetic polarity stratigraphy yields the following estimated magnetobiochronology: Cretaceous/Tertiary boundary (just below anomaly 29): 66.4 Ma; Paleocene/Eocene (between anomalies 24 and 25): 57.8 Ma; Eocene/Oligocene (between anomalies 13 and 15): 36.6 Ma; Oligocene/Miocene (mid-anomaly 6C): 23.7 Ma.

The Eocene is seen to have expanded chronologically (~21 my) at the expense of the Paleocene (~9 my) and is indeed the longest of the Cenozoic epochs. In addition, magnetobiostratigraphic correlations require adjustments in apparent correlations with standard marine stage boundaries in some cases (particularly in the Oligocene). Finally we present a correlation between standard Paleogene marine and terrestrial stratigraphies.

MAGNETOBIOSTRATIGRAPHY OF DSDP LEG 72 SITES 515-518, RIO GRANDE RISE (SOUTH ATLANTIC)

W.A. Berggren, N. Hamilton, D.A. Johnson, C. Pujol, W. Weiss, P. Cepek and A. Gombos

In this paper we present magnetobiostratigraphic correlation charts for each of the four sites occupied during DSDP Leg 72. Microfossil zonal boundaries and magnetic polarity determinations for Sites 515 through 518 are summarized in Figures 1 through 4, respectively. In the text we shall discuss in some detail the correlations derived for the Paleogene and late Cretaceous (Coniacian-Maestrichtian) of Site 516, because of the value of this site as a stratigraphic reference section for the South Atlantic. The Neogene magnetobiostratigraphy of Site 516 has been treated in detail elsewhere (Berggren, Aubry and Hamilton, this volume), and will not be discussed further in this synthesis chapter.

EVIDENCE FOR PRIMARY CONTROL OF THE DISTRIBUTION OF CERTAIN ATLANTIC OCEAN BENTHIC FORAMINIFERA BY DEGREE OF CARBONATE SATURATION

M.L. Bremer and G.P. Lohmann

The distribution of certain Atlantic Ocean benthonic foraminifera are most consistently correlated with the degree of saturation of seawater with respect to calcium carbonate. Based on this relationship, it may be possible to recognize changes in "paleosaturation" in the deep sea from fossil benthonic foraminifera.

DISTRIBUTION OF HOLOCENE DEEP-SEA
BENTHONIC FORAMINIFERA IN THE
SOUTHWEST INDIAN OCEAN

Bruce H. Corliss

The distribution of deep-sea benthonic foraminifera in the southwest Indian Ocean is examined based on a quantitative analysis of 40 trigger core top samples. Principal component analysis reveals two major assemblages within the region. One assemblage is dominated by Epistominella umbonifera and is found between 3600 and 4800 m water depth associated in general with cold (θ = -0.3° to 0.8°C), low salinity (34.66 to 34.72^0/oo) Antarctic Bottom Water in the Crozet Basin and in fracture zones and on the flanks of the Southwest Indian Ridge. A second assemblage, dominated by Planulina wuellerstorfi, Globocassidulina subglobosa, Astrononion echolsi, and Pullenia bulloides, is found between 1600 and 3800 m on the Crozet Plateau, Madagascar Ridge, Central Indian Ridge, and Southwest Indian Ridge associated in general with relatively warm (θ = 0.8° to 2.6°C), high salinity (34.72 to 34.76^0/oo) North Atlantic Deep Water. The third principal component divides the P. wuellerstorfi assemblage into two subgroups. One subgroup is dominated by Epistominella exigua, P. bulloides, P. wuellerstorfi, and A. echolsi and a second subgroup is dominated by G. subglobosa. The distribution of the E. umbonifera assemblage and previous hydrographic studies suggest that AABW flows as a western boundary contour current in the Crozet Basin and penetrates fracture zones in the Southwest Indian Ridge between 55°E and 57°E and near 66°E, as it travels northward into the Madagascar and Mascarene Basins.

The faunal-water mass associations in this study and from the southeast Indian Ocean are compared and show that the most notable faunal difference is the absence of Uvigerina as a dominant taxon in the present study. A comparison of dissolved oxygen and Uvigerina abundance data shows that oxygen is not a major influence upon the distribution of Uvigerina in the deep sea.

A correlation analysis of the faunal data and water depth, potential temperature, in situ temperature, salinity, dissolved oxygen, and 1-Ω, an index of calcium carbonate undersaturation, was carried out to determine the relationships between faunal and hydrographic data. The 2nd principal component has a significant positive correlation at the 99.9°/° level with temperature, and negative correlations with water depth and 1-Ω. A general faunal-water mass correlation exists, but it is not possible to determine which variable is controlling the faunal distributions.

SEASONAL CHANGES IN THE ISOTOPIC
COMPOSITION OF PLANKTONIC FORAMINIFERA
COLLECTED IN PANAMA BASIN SEDIMENT TRAPS

W.B. Curry, R.C. Thunell and S. Honjo

Isotopic analyses have been performed on five species of planktonic foraminifera collected in two deployments of PARFLUX Mark II sediment traps in the Panama Basin. The automated sampling system on the traps provided 4 one-month samples from 29 July to 16 November 1979 and 6 two-month samples from December 1979 to November 1980.

The $\delta^{18}O$ values of Globigerinoides ruber and Globigerinoides sacculifer in this region are dominantly affected by a low salinity surface layer that forms during the early winter. These species each show a 1 ^{0}/oo total range in $\delta^{18}O$. The $\delta^{18}O$ values of the deeper-dwelling Globorotalia menardii, Neogloboquadrina dutertrei, and Globorotalia theyeri show smaller seasonal change in $\delta^{18}O$. The $\delta^{13}C$ values of G. ruber and G. sacculifer exhibit small seasonal changes (0.35 and 0.4 ^{0}/oo respectively) despite large seasonal changes in surface water productivity. The deeper-dwelling species exhibit only slightly larger changes in $\delta^{13}C$ (up to 0.55 ^{0}/oo) throughout the year. All deep-dwelling species exhibit minimum or near minimum $\delta^{13}C$ values during February and March, which is the period of maximum upwelling and primary productivity. Seasonal variations in the flux of foraminifera in the water column at this location will have only a small effect on the isotopic composition of the sediment assemblage; extreme values of $\delta^{18}O$ and $\delta^{13}C$ do not occur during the periods which are associated with the high flux of foraminiferal tests.

CENOZOIC RADIOLARIA FROM THE BRAZIL BASIN AND RIO GRANDE RISE

D.A. Johnson

The Neogene of the southwestern Atlantic is virtually barren of biogenic silica. Of the four sites drilled on Leg 72, only two contained identifiable radiolarian specimens. In the southwestern Brazil Basin (Site 515), radiolarians are present only from the late Oligocene (Anomaly 8, ca. 28 my B.P.) to the middle Miocene (Zone NN8, ca 11.5 my B.P.). On the Rio Grande Rise (Site 516), radiolarians are present only within a short interval of the early Miocene (Zones N5-N6, ca 18 to 20 my B.P.). The abrupt cessation of silica deposition in the late Middle Miocene is characteristic of many drill sites in the tropical and temperate Atlantic, and implies that a major oceanographic "threshold" was exceeded at this time, allowing the Atlantic waters to become relatively silica-deficient. Silica is notably more abundant in the Oligocene-Miocene of deep regions where carbonate preservation is poor (Site 515) than in equivalent carbonate-rich strata nearby (Site 516). This discrepancy suggests that calcareous microfossils and the associated pore water chemistry may act to enhance post-depositional dissolution of biogenic silica tests, whereas carbonate-free clays may provide a more favorable chemical environment for silica preservation.

PALEOCIRCULATION OF THE SOUTHWESTERN ATLANTIC

David A. Johnson

The Cenozoic history of the abyssal circulation of the southwestern Atlantic is punctuated by tectonically- or climatically-controlled "threshold" events, triggered by the changing geophysical boundary conditions associated with the plate tectonic development of the basins. The initial rifting of the South Atlantic during the early Cretaceous created silled basins on either side of the proto-Mid Atlantic Ridge, within which accumulated a sedimentary succession of evaporitic, terrigenous, and carbonaceous facies. The east-west volcanic lineaments of the Rio Grande Rise-Walvis Ridge and the Ceara-Sierra Leone Rises effectively blocked the meridional exchange of deep waters for at least the first 20-30

millions years of South Atlantic history. Pelagic biogenic sedimentation persisted through the equable climates of the late Cretaceous and early Paleogene, with no evidence of significant bottom current activity. The aseismic Rio Grande Rise extended above sea level during the initial episodes of vulcanism in the Santonian-Coniacian, and subsided at near-normal crustal subsidence rates for the first 35 my of its history. A major thermal episode during the middle Eocene (47 Ma) re-elevated large areas of the Rise to sea level, with extensive vulcanism, block faulting, and debris flows associated with this event. The shallowest guyots of the Rise subsided below sea level in the Oligocene, and the Rise has continued to subside since then.

Pelagic sedimentation in the deep basins bordering the Rio Grande Rise was interrupted by a major erosional episode beginning in the late Eocene to early Oligocene. Spreading of the Greenland-Scotland ridge initiated deep thermohaline flow from the northern Atlantic, advecting oxygen-rich, high-salinity water into the South Atlantic at mid-depths. This high-salinity water, or "proto-North Atlantic Deep Water" (NADW), extended to the perimeter of the Antarctic continent, and mixed with the ambient cold surface waters to form a "proto-Antarctic Bottom Water" (AABW). Subsequent fluctuations in the flow intensity of NADW and AABW are closely linked, because the presence of high-salinity water of North Atlantic origin appears to be an essential condition for the formation of AABW around the Antarctic perimeter.

During the latest Miocene, the high-salinity Mediterranean outflow ceased as a result of the closure of the Gibraltar sill, and NADW flow into the central and south Atlantic was shut off. As a result, the blocking of Circumpolar Water (CPW) by NADW ceased, and CPW expanded its northward penetration and its vertical extent within the South Atlantic. The re-initiation of the Mediterranean outflow in the early Pliocene (between 5.0 and 4.0 Ma) and the subsequent re-initiation of NADW and AABW produced extensive erosional hiatuses below 2000 meters on the Rio Grande Rise, in some instances eroding much of the underlying Upper Miocene sediments as well. The interval from 4.0 to 3.8 Ma is associated with a major cooling trend in the Southern Ocean, indicated by a northward displacement of siliceous sediments, the expansion of the west Antarctic ice sheet, and major glaciation in Argentine Patagonia. Antarctic ice sheet may have been a direct consequence of the renewal of NADW from the north (e.g. Schnitker, 1980).

Production of proto-NADW and proto-AABW diminished markedly between 3.8 and 3.2 Ma, and circumpolar flow intensified, resulting in widespread erosion over Maurice Ewing Bank, and allowing a relatively youthful neo-Circumpolar Water (CPW) to penetrate well into the South Atlantic. At 3.2 Ma the Pliocene climates deteriorated rapidly with the growth of northern hemisphere ice sheets, co-occurring with a major intensification of both NADW and AABW. We suggest that the closure of the Panama isthmus was the principal contributing factor, by blocking the westward Tethyan flow in the tropical Atlantic and strengthening the northward transport of the shallow western boundary current (i.e., a "proto-Gulf Stream"). This current, in turn, supplied warm surface water adjacent to eastern Canada as a source for evaporation to build the Arctic ice sheets, and advected high-salinity subtropical waters into the northeastern Atlantic to intensify NADW production.

The latest Pliocene and Quaternary are marked by parallel intensifications and weakenings of NADW and AABW, with the flow perhaps strongest at 40 Kyr intervals corresponding to maxima in summer insolation and oribital tilt. These pulsations should be reflected in periods of thickening and thinning of the broad transition zone between NADW and AABW, rather than as vertical migrations of a sharp "boundary" separating the two water masses.

In press: Initial Reports of the Deep Sea Drilling Project, Vol. 72.

Supported by: NSF Grant OCE80-25208.

WHOI Contribution No. 5279.

REGIONAL OCEANOGRAPHIC SETTING OF THE SOUTHWESTERN ATLANTIC

David A. Johnson

The southwestern Atlantic is a region where several major water masses converge, and as such is a suitable target area for a number of important paleoceanographic drilling objectives. The flanks of the Rio Grande Rise intersect each of these water masses; from shallowest to deepest, these are: Antarctic Intermediate Water (AAIW), 900-1000 meters; Upper Circumpolar Water (UCPW), 1300-1550 meters; North Atlantic Deep Water (NADW), 2300-3200 meters; and Antarctic Bottom Water (AABW), below ~ 4000 meters. The pelagic sediments draping the Rise and in the deeper Vema Channel and Brazil Basin were the focus of several drilling objectives during DSDP Leg 72. These included: (a) determining the time of onset of AABW flow through the Vema

Channel; (b) establishing when the initial production of a northern source of bottom water occurred; (c) examining the effects of major episodes of ice growth in polar regions upon the production and strength of deep thermohaline currents; (d) investigating the effeacts of major tectonic reconfigurations upon the thermohaline circulation; and (e) analyzing cores obtained by the Hydraulic Piston Corer (HPC) to obtain time-series observations of geological "fingerprints" of paleocirculation, and using these records to derive a better understanding of the teleconnective linkages between the major water masses.

In press: Deep Sea Drilling Project, Vol. 72.

Supported by: NSF Grant OCE80-25208.

WHOI Contribution No. 5188.

SHAPE VARIATION IN Spiroplectammina spectabilis (GRZYBOWSKI)

Michael A. Kaminski

The morphology and intraspecific variation of Spiroplectammina spectabilis (Grzybowski) is investigated based upon topotype material. Linear measurements and eigenshape analyses of species of Spiroplectammina described from California show them to be conspecific with S. spectabilis. Two ecophenotypic forms are distinguished: S. spectabilis forma trinitatensis - a robust Eocene variety, and S. spectabilis forma perplexa, a minute, compressed form.

In press: Acta Paleontologica Polonica.

Supported by: A consortium of oil companies.

WHOI Contribution No. 5257.

EIGENSHAPE ANALYSIS OF MICROFOSSILS: A GENERAL MORPHOMETRIC PROCEDURE FOR DESCRIBING CHANGES IN SHAPE

G.P. Lohmann

A general morphometric procedure is described that organizes collections of microfossil outlines according to their shape. It involves representing variation observed among a collection of shapes by the least possible number of different shapes. Since these are determined as empirical orthogonal shape functions, eigenfunctions, of the observed shapes, the procedure is termed eigenshape analysis. Observed shapes are arranged and their

shape differences systemized by reference to the determined eigenshape functions. The well-known ecophenotypic shape variation with latitude exhibited by the Pleistocene planktonic foraminiferan Globorotalia truncatulinoides (d'Orbigny) serves as an example.

EIGENSHAPE ANALYSIS PROGRAMS

G.P. Lohmann and C.R. Denham

Eigenshape analysis is a morphometric procedure for arranging oriented microfossils according to similarities and differences in the shape of their planar outlines. This involves derivation of a set of empirical orthogonal shape functions by an eigenfunction or principal components analysis of a matrix of correlations between the shapes. Only a brief description of the method is given here, as a thorough presentation and an application of eigenshape analysis are given elsewhere (Lohmann, in press; Lohmann and Malmgren, in press).

EQUATORWARD MIGRATION OF Globorotalia Truncatulinoides ECOPHENOTYPES THROUGH THE LATE PLEISTOCENE: GRADUAL EVOLUTION OR OCEAN CHANGE

G.P. Lohmann and Bjorn A. Malmgren

The biogeography of differences in average shape of the modern planktonic foraminifer Globorotalia truncatulinoides (d'Orbigny) exhibits systematic relationships to changes in the ocean's surface environment. Comparison of these shape changes, as they exist today in the southern hemisphere, with fossil shapes preserved in a Late Pleistocene record from the South Atlantic Ocean shows that the biogeography of G. truncatulinoides ecophenotypes has changed markedly through time. Beginning at least 700,000 years ago, and continuing up to the present time, there has been a gradual but clear

migration of certain morphotypes of G. truncatulinoides toward lower latitudes. The history of this migration bears no simple relationship to the cyclic changes that characterize the late Pleistocene. We conclude that either (1) phenotypic variants of G. truncatulinoides reflect some previously unmeasured, gradually changing aspect of late Pleistocene oceans, or (2) we are witnessing a gradual evolution of the environmental preferences of G. truncatulinoides.

CENOZOIC BENTHIC FORAMINIFERA

Kenneth G. Miller

I will outline several examples where Cenozoic benthic foraminifera have figured in the interpretation of paleoceanographic and sea-level changes. Both shallow-(neritic) and deep-water (bathyal-abyssal) applications will be presented, although I will stress the relationships among deep-sea benthic foraminifera, other indicators of paleoenvironment, and abyssal circulation changes. Ecologic, paleoecologic, and biogeographical controls on benthic foraminiferal distribution are dealt with elsewhere in this volume. Historical background, sampling methods, preservation, and studies of larger foraminifera are omitted; for these the reader is referred to other reviews (Boltovskoy and Wright, 1976; Douglas, 1979; Douglas and Woodruff, 1982; Adams, 1967).

LATE PALEOGENE (EOCENE TO OLIGOCENE) PALEOCEANOGRAPHY OF THE DEEP BAY OF BISCAY: BENTHIC FORAMINIFERAL EVIDENCE

Kenneth G. Miller

A major change in benthic foraminiferal assemblages occurred in the deep Bay of Biscay (>3 km water; DSDP Sites 119 and

Site 400A) between early middle Eocene and earliest Oligocene. Predominant Eocene deep-sea taxa (Nuttallides truempyi, Clinapertina spp., Abyssamina spp.) and associated rarer species became extinct in this interval. These extinctions were followed by an increase in abundance of bathymetrically wide-ranging and stratigraphically long-ranging taxa: Globocassidulina subglobosa, Oridorsalis spp., Gyroidinoides spp., and the Cibicidoides ungerianus plexus. The extinctions cannot be dated precisely from the stratigraphic record recovered to date in the Bay of Biscay; however, the replacement of the N. truempyi-dominated assemblage has been noted previously in the deep South Atlantic/Caribbean as occurring within the middle Eocene. No major faunal changes are noted within the Eocene at the shallower Site 401 (~2 km water) in the Bay of Biscay. During the Oligocene, Nuttallides umbonifera replaces the Eocene species N. truempyi as the predominant deep-sea benthic foraminifera, reaching peak abundance in the middle Oligocene at Sites 119 and Site 400A. In the modern oceans, the abundance of N. umbonifera is positively correlated with increased corrosiveness of bottom water, while at Site 119 the abundance of Nuttallides spp. is negatively correlated with $\delta^{13}C$ values in benthic foraminifera. As lower $\delta^{13}C$ values are often associated with older water masses, large numbers of Nuttallides spp. are thought to reflect older, and more corrosive, bottom water. The faunal data and oxygen and carbon isotopic data are compared with a circulation model derived from North Atlantic seismic stratigraphic studies to show that old, warm, corrosive and sluggish Eocene bottom water was replaced by younger, colder, less corrosive, more vigorously circulating bottom water of northern origin by the early Oligocene. Faunal and isotopic data suggest that bottom water became older and more corrosive again in the middle Oligocene, reflecting a reduction in circulation that can also be inferred from the seismic record in the nearby Rockall Plateau region.

In press: Marine Micropaleontology.

SEASONAL VARIATION IN THE FLUX OF PLANKTONIC FORAMINIFERA: TIME SERIES SEDIMENT TRAP RESULTS FROM THE PANAMA BASIN

R.C. Thunell, W.B. Curry and S. Honjo

A mooring array with three automated sediment traps capable of collecting time series samples was deployed in the Panama Basin for one year beginning in December of 1979. A series of six consecutive two-month long samples was collected at each of three depths (890, 2590 and 3560 m) in order to examine seasonal variation in the flux of planktonic foraminifera, and evaluate the contribution of foraminifera to the total carbonate flux.

The flux of the larger planktonic foraminifera ($250-500\mu$ and $500-1000\mu$) is greatest during February-March when upwelling is most intense in the Panama Basin. In contrast, the maximum flux of the smaller foraminifera ($125-250\mu$) is associated with a phytoplankton bloom during the summer months (June through September). This size-dependent flux pattern appears to be a species specific effect. The flux of the larger foraminifera is dominated by the deeper-dwelling, non-spinose forms (ie. Neogloboquadrina dutertrei and Globorotalia theyeri), while the flux of the smaller foraminifera consists predominantly of shallow-dwelling, spinose species (ie. Globigerinoides ruber, G. sacculifer and G. conglobatus). Although the magnitude of the flux varied throughout the year, the average weight of individual foraminiferal tests in different size fractions showed no seasonal variability.

With the exception of the June-July period when there was a major coccolith bloom, planktonic foraminifera greater than 125μ account for between 28 and 34 percent of the total carbonate flux at this location. During the coccolith bloom, planktonic foraminifera accounted for less than 2 percent of the total carbonate flux. Planktonic foraminifera in the $250-500\mu$ size range are the most significant contributors to the overall particulate flux, accounting for roughly 70 to 80 percent of the total foraminiferal fluxes measured at the three trap depths.

In press: Earth and Planetary Science Letters.

PALEOCENE-EOCENE BATHYAL AND ABYSSAL BENTHIC FORAMINIFERA FROM THE ATLANTIC OCEAN

R.C. Tjalsma and G.P. Lohmann

This paper reconstructs the original distributions of Paleocene and Eocene deep water benthic foraminifera throughout the Atlantic Ocean.

Several bathymetrically distinct biofacies are recognized during this period; however, Paleocene species typically have broadly overlapping bathymetric ranges, while Eocene species tend to be more bathymetrically restricted.

The deepest biofacies is consistently dominated by Nuttallides spp.; this is also the longest ranging stratigraphically, from Early Paleocene through late Middle Eocene. This Nuttallides biofacies expanded its bathymetric range from abyssal depths to middle bathyal depths through the Paleocene, replacing an assemblage of relic Cretaceous species dominated by Gavelinella beccariiformis. Gradual retreat into shallower water and ultimate extinction of this G. beccariiformis biofacies at the Paleocene/Eocene boundary appears to be the most dramatic event in the evolution of Mesozoic and Cenozoic deep-water benthic foraminifera. After this extinction event, the rate of origination of new species increased, the Nuttallides biofacies returned to abyssal depths and extinction in the late Middle Eocene, and two taxonomically and bathymetrically distinct biofacies developed in the Early and Middle Eocene. These two biofacies (a deeper one characterized by Globocassidulina subglobosa, Gyroidinoides spp. and Cibicidoides ungerianus and a shallower one dominated by Lenticulina spp.) maintained their depth distribution to the end of the Eocene.

Biostratigraphic usefulness of deep water benthic foraminifera is complicated by the occurrence of extinctions and originations at different times at different depths. However, by selecting associations of benthic foraminifera with the widest possible depth ranges, five informal biostratigraphic faunal units subdividing the Paleocene-Early Eocene are proposed.

No evidence was found in this study for any relationship between the distribution and evolution of Paleocene and Eocene deep-water benthic foraminifera and the isotopically estimated thermal history of the deep ocean.

One new genus, Clinapertina, is defined. Six new species are described:

Tritaxia paleocenica, Lenticulina whitei, Bulimina glomarchallengeri, Clinapertina inflata, C. complanata, and C. subplanispira.

In Press: Micropaleontology, Special Volume No. 4.

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WHOI Contribution No. 5113.

PETROLOGY

CHROMIAN SPINEL AS A PETROGENETIC INDICATOR IN OCEANIC ENVIRONMENTS

Henry J.B. Dick and Thomas Bullen

The composition of chromian spinel in alpine-type peridotites has a large reciprocal range of Cr and Al with increasing Cr No. (Cr/(Cr+Al)) reflecting increasing degrees of partial melting in the mantle. Using spinel compositions, alpine-type peridotites can be divided into three groups. Group I - Cr No. (Cr/(Cr+Al)) <0.60, Group III - CR No. >0.60, and Group II which spans the range of Groups I and III spinel compositions. Spinels in abyssal peridotites lie entirely within the Group I spinel field, making ophiolites with Group I alpine-type peridotites the most likely candidates for sections of ocean lithosphere formed at a classic mid-ocean ridge. The only modern analogues for Group III spinels are found in arc-volcanics, including boninites, andesites and dacites, and in continental and Southeastern Alaskan layered intrusions. Accordingly, we infer a sub-volcanic arc petrogenesis for Group III alpine-type peridotites. Group II alpine-type peridotites apparently reflect composite origins such as the formation of an island-arc on ocean crust resulting in large variations in the degree and provenance of melting over relatively short distances. The essential difference between Group I and Group III appears to be the presence or absence of diopside in the residue at the end of melting.

Based on an examination of co-existing rock and spinel compositions in extrusive lavas, it appears that spinel is a sensitive indicator of melt composition and pressure of crystallization. The close similarity of spinel composition fields in genetically related basalts, dunites and peridotites at localities in the oceans and in ophiolite complexes indicates that its

composition reflects the degree of melting in the mantle source region. Accordingly, we infer from the restricted range of spinel compositions in abyssal basalts that the degree of mantle melting beneath mid-ocean ridges is generally limited to that found in Group I alpine-type peridotites.

In press: Contributions to Mineralogy and Petrology.

FERROBASALTS FROM THE SPIESS RIDGE SEGMENT OF THE SOUTHWEST INDIAN RIDGE

A.P. le Roex, H.J.B. Dick, A.M. Reid and A.J. Erlank

Highly vesicular, microporphyritic basaltic rocks have been dredged from the slow spreading Spiess Ridge segment of the Southwest Indian Ridge. All the samples recovered are hyalocrystalline with plagioclase, clinopyroxene and olivine as phenocryst and microphenocryst phases. Titanomagnetite occurs as euhedral microphenocrysts in some of the more evolved samples. In terms of bulk rock and quench glass chemistry the lavas are characterized by their highly evolved compositions (e.g. $FeO^* = 10.3 -14.2$ percent; $TiO_2 = 2.0 - 3.4$ percent; $K_2O = 0.50 - 1.1$ percent; $MgO = 6.0 - 3.5$ percent; $Zr = 160 - 274$ ppm; $Nb = 14 - 32$ ppm), and can be classified as ferrobasalts. Isotopic and incompatible element ratios of the lavas (e.g $^{87}Sr/^{86}Sr = 0.70325 - 0.70333$; $Zr/Nb = 8.4-11.3$; $Y/Nb = 2.3-1.4$) indicate their strongly 'enriched' nature (see also Dickey et al. [6]).

Quantitative major and trace element modeling indicates that most of the compositional variations observed can be attributed to low pressure fractional crystallization of plagioclase, clinopyroxene and minor olivine. The range in composition can be accounted for by up to 65 percent fractional crystallization.

We suggest that the extreme differentiation of the Spiess ridge lavas is related not to spreading rate, but to rate of magma supply. The basaltic melts appear to have evolved in a newly established zone of magma activity, associated with the most recent northward jump of the Bouvet Triple Junction, where they were effectively isolated from significant admixture of primitive magmas.

PHYSIOGRAPHY

MORPHOLOGY OF THE GULF OF MAINE AND GEORGES BANK

Elazar Uchupi and J.A. Austin

The continental shelf off New England is unusually deep and irregular consisting of the Gulf of Maine and Georges Bank. The gulf is a rectangular depression with an average depth of 150 m. It is connected to the open sea by Northeast Channel which is over 200 m deep. Georges Bank at the mouth of the Gulf of Maine rises more than 100 m above the gulf. Along the crest of the bank is a series of northwest trending shoals. The continental slope south of Georges Bank is unusually steep and is incised by submarine canyons. Beyond the slope is the continental rise, a carbonate-terrigenous sediment wedge. The shelf's and slope's topography is due mainly to Mesozoic carbonate deposition on the outer shelf/slope, Tertiary fluvial erosion and late Pleistocene (Wisconsin) glacial erosion and deposition. The fluvial/glacial terrain on the shelf was modified to its present shape during the Holocene transgression and by tidal currents since then.

In Press: Georges Bank Atlas.

SEDIMENTOLOGY

ORGANIC FILMS IN SURFACE WATERS OFF EASTERN ASIA

K.O. Emery, Ian A. Johns and Susumu Honjo

SEM examination of filters from samples of surface waters over continental shelves and deeper areas off eastern Asia reveal the presence of irregular organic films that are longer, cover more filter area, and have more tapered edges in samples from

nearshore than offshore regions. Associated diatoms include species diagnostic of coastal environments. Films and coastal diatoms are most abundant in waters above continental shelves where river discharges have caused the waters to be more dilute than 33.5 °/oo salinity. Farther from shore both films and skeletal elements are broken and partly dissolved. Skeletal elements, fecal matter, and other debris are trapped or adhere to the films, which therefore provide a concentrated food source for small organisms beyond nearshore regions of high primary productivity. The films contribute an unknown percentage of the total organic matter that reaches bottom sediments.

PARTICULATE SIZE SPECTRA, BEHAVIOUR AND ORIGIN OF NEPHELOID LAYERS OVER THE NOVA SCOTIAN CONTINENTAL RISE

I.N. McCave

Samples of suspended sediment and light transmissometer observations were taken on two occupations of a transect of the Nova Scotian continental rise in 1980. Initial low suspended sediment concentrations were followed by high values ten days later. Patches of higher concentration were found on the edges of zones of cold ($\theta < 1.78°C$) water. Particle volume concentrations in the size range 1.26-32 μm measured by Coulter Counter correlate linearly with light beam attenuation coefficient. Correlation between particle volume and weight concentration indicates lower apparent particle density for low-concentration suspensions, a feature that is attributed to aggregation during aging of the suspension. Particle size distributions measured by Coulter Counter on 10 cm^3 samples show unimodal form with a peak at ~ 4 μm in high concentrations near the bed changing to a bimodal form with an additional mode at ~ 16 μm in low concentrations high above the bed (500 and 1000 m.a.b.). The presence of coarse mode at 1000 m.a.b. coupled with its increase in the lower 250 m of the water column suggests that it both settles from the surface and is resuspended from the bed.

SIZE SPECTRA AND AGGREGATION OF SUSPENDED PARTICLES IN THE DEEP OCEAN

I.N. McCave

The removal of particles from surface and mid-water in the oceans normally requires their aggregation into larger units having a settling speed greatly in excess of the original particles. This argument has been presented and corroborated by several authors including Rex and Goldberg (1958), Schrader (1971), McCave (1975), Honjo (1976), and in a recent eruption of papers based on sediment-trap data. The size distribution of suspended particles is a function of several variables including source and nature of the particles, physical or biological processes of aggregation and "age" of the suspension. In this paper the physical processes controlling formation of aggregates are examined, their rates compared and their relative importance evaluated. A large body of theory and experience concerning particle interactions has been developed by aerosol physicists and by chemical engineers treating aqueous suspension over many decades. Recently this work has been made easily accessible in the books of Friedlander (1977), Twomey (1977) and Pruppacher and Klett (1978). Another purpose of this paper is to examine the implications of the aerosol and experimental work for the hydrosols of the deep sea.

DIMENSIONS AND SINKING SPEEDS OF TROPICAL RADIOLARIAN SKELETONS FROM THE PARFLUX SEDIMENT TRAPS

Kozo Takahashi

Length, width and projected area (58 species) and weight (53 species) of radiolarian skeletons, mainly from the Panama Basin PARFLUX sediment trap (5°21.8'N, 82°01.4'W) samples, were measured. Volume and density contrast were computed. The measured mean weight values for the examined species range from 0.05μg/shell to 24μg/shell. The weight is best correlated with projected area among the studied size dimensions of Radiolaria as a whole group. The density contrast of the radiolarian skeletons, relative to seawater, generally falls between 0.01 and 015 g/cm^3 and appears to be constant with an order of magnitude increase of the shell diameter.

The sinking speeds of specimens of 55 radiolarian species measured in 3, 10 and 20°C seawater range from 13 to 416 m/day. Despite the wide variety of morphology between the species, the sinking speed is best correlated with weight/shell with reasonably small deviations from a regression line. Using the sinking speeds, residence times of the 55 species in the 5 km pelagic water column range from 2 weeks to 14 months.

In Press: WHOI Technical Report.

Supported by: NSF Grant OCE80-19386.

RADIOLARIA: SINKING POPULATION, PRODUCTION RATE AND RESIDENCE TIME

Kozo Takahashi

A new method is presented for estimating sinking population, rate of production and residence time in the living zone for Radiolaria. This method employs vertical flux measurements from PARFLUX sediment traps and laboratory measurements of sinking speed.

The estimated population sinking through the oceanic water column is approximately equal to the standing stock at several hundred meters depth reported from direct measurements by other workers. The rate of production of total Radiolaria was estimated to be approximately 80 shells/m^3/day in tropical Atlantic and Pacific Stations and 230 shells/m^3/day in the Panama Basin. The production of Nassellaria is greater than that of the other suborders. The average residence time for Radiolaria in the living zone was estimated to be between 12 and 56 days.

The standing stock and vertical distribution of Radiolaria are generally similar in different parts of the ocean despite differences in temperature, regional primary production, sampling method and season of investigation.

In press: Journal of Marine Research.

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WHOI Contribution No. 5159.

RADIOLARIAN SKELETONS: SIZE, WEIGHT, SINKING SPEED AND RESIDENCE TIME IN TROPICAL PELAGIC OCEANS

Kozo Takahashi and Susumu Honjo

Dimensions of hand-picked radiolarian skeletons, mainly from the Panama Basin PARFLUX sediment trap (5°21.8'N, 82°01.4'W)

samples, were measured; they are length, width and projected area (58 species) and weight (53 species). Volume and density contrast were computed. The measured mean weight values for the examined species range from 0.05 µg/shell to 24 µg/shell. These values appear to be orders of magnitude greater than weight values for preserved radiolarians from the bottom sediments. Selective dissolution of many large-sized species accounts for this. The weight is best correlated with projected area among the studied size dimensions of Radiolaria as a whole group. The density contrast of the radiolarian skeletons, relative to seawater, generally falls between 0.01 and 0.5 g/cm^3 and appears to be constant with an order of magnitude increase of the shell diameter.

The sinking speeds of specimens of 55 radiolarian species measured in 3, 10 and 20°C seawater range from 13 to 416 m/day. Despite the wide variety of morphology between the species, the sinking speed is best correlated with weight/shell with reasonably small deviations from a regression line. The observed sinking speeds are relatively close to those predicted by Stokes Law up to approximately 250 µm in diameter, but deviate (toward slower speeds) above 250 µm with increasing Reynolds number. Using the sinking speeds, residence times of the 55 species in the 5 km pelagic water column range from 2 weeks to 14 months. Based on the residence time and vertical flux measurements, the majority of polycystine Radiolaria appear to reach the bottom without substantial loss in their assemblages. Large phaeodarian radiolarians appear to reach the water-sediment interface relatively quickly and ultimately dissolve there. Small-sized phaeodarians dissolve en route during sinking.

In Press: Deep-Sea Research.

Supported by: NSF Grant OCE80-19386.

WHOI Contribution No. 5169.

TRANSFER OF WASTE AND SEDIMENT FROM THE YANGTZE RIVER TO THE EAST CHINA SEA JUNE 1980

Yang Zuo-sheng, John D. Milliman and Michael G. Fitzgerald

The Yangtze River, fourth largest in the world in terms of sediment discharge, contributes about 500 x 10^6 t annually to the East China Sea. A disproportionate part of the load is carried after peak summer discharge, presumably the result of draining the rice fields. During a week-long study of the estuary, greatest

water discharge was observed in the North
Passage. Suspended sediment concentrations
were highest in the South Channel of the
South Passage, although in contrast to the
North Passage little of the suspended
sediment was coarse. The high sediment
concentrations in the South Channel appear
to be the result of oscillatory (net
transport upstream) movement of material,
in contrast to the marked seaward transport
measured in the North Passage.

DEPARTMENT OF OCEAN ENGINEERING

Robert C. Spindel, Department Chairman

OCEAN ENGINEERING

C O A S T A L   D Y N A M I C S

MOVEABLE BED ROUGHNESS IN UNSTEADY OSCILLATORY FLOW

William D. Grant and Ole Secher Madsen

A model to predict the roughness in unsteady oscillatory flows over moveable, non-cohesive beds is presented. The roughness over moveable beds is shown to be a function of the boundary shear stress, rather than a fixed geometrical scale as is the case for fully rough turbulent boundary shear flows over immobile beds. The model partitions the roughness into two distinct contributions. These two contributions are due to the form drag around individual bed forms and to the near-bed sediment transport. The form drag over the bed forms is treated explicitly as a function of the boundary geometry and shear stress. The ripples are predicted as a function of the local skin friction and a semi-empirical expression is derived using standard law-of-the-wall arguments, which gives the ripple or form roughness as a function of the boundary geometry. The ripple roughness is found to be proportional to the product of the ripple steepness and height. Favorable comparison of the form drag model with the results of Bagnold's (1946) fixed ripple study is found.

The value of z_0 associated with intense sediment transport in oscillatory flow over a flat bed is determined from Carstens et al.'s (1969) experiments. This value is found to be 7 or 8 grain diameters. An expression is derived for the roughness associated with the maximum thickness of a near-bottom sediment transporting layer consistent with Owen's (1964) roughness hypothesis for saltation of uniform grains in air. At large values of the boundary shear stress relative to the critical value for initial sediment motion, the derived expression is similar to the results of Smith and McLean's (1977) unidirectional flow approach modified for oscillatory flow.

The total roughness model is found to compare favorably with Carstens et al.'s (1969) data. In contrast to Smith and McLean's (1977) steady flow findings, the results here show that when ripples are present, they account for a significant portion of the boundary roughness.

THE EFFECTS OF BIOTURBATION ON THE INITIATION OF MOTION OF INTERTIDAL SANDS

William D. Grant, Lawrence F. Boyer and Lawrence P. Sanford

The results of laboratory flume experiments to study initiation of sediment motion in natural marine sediments (fine to medium sands) are reported. Critical shear stresses were determined for sediment cores from an intertidal region for bed conditions corresponding to; (1) the field state at low tide and (2) a bioturbated state. Cores were taken for all seasons of the year over a four year period. Critical stresses for the natural sediment are compared with stress values for the same sediment in an abiotic (control) state. Critical stresses for the control cores agree well with predictions from Shields curve. In the field state, biological cohesion in the sediment surface increases critical stresses relative to Shields, but never by more than a factor of two. This is well within the normal error bars on Shields curve. Reworking of the sediment surface lowers this value back toward Shields. The magnitude of cohesion and reworking vary seasonally, being highest in the late fall and lowest in the winter. No simple relationship between metabolic activity, temperature and stabilization is supported by the data.

Differences in critical stress values for cores in their initial field state, and in a bioturbated state, indicate that the stability of intertidal sediments may vary over a tidal cycle. The study demonstrates that without controlled experiments, biological processes should not be termed stabilizing or destabilizing because the types of organisms present make relatively different contributions to the sediment stability, and it is the sum total of all effects which is of concern. We suggest that the Shields initiation of motion criterion be used as a standard to define biological stabilization or destabilization.

COMPUTER SCIENCE

A COLLECTION OF FORTRAN INTERACTIVE PROGRAMMING AIDS (FIPA)

Roger Goldsmith

This report documents a collection of subroutines written to assist the FORTRAN user who is programming in an interactive environment. With the advent of the VAX computer, the Woods Hole programming community now has a facility that is primarily an interactive environment. This type of environment lends itself to a different style of programming, one that allows the user to iteratively communicate with the program. These routines assist the FORTRAN user in developing such programs by providing the supporting software necessary for a command word style of processing. The programs include:

1. a dictionary, used to define command words,
2. a simple, user defined, command record parser,
3. easy access to on-line information, or "HELP" files,
4. display of associated variable values,
5. error handling conventions.

WHOI Technical Memorandum No. 1-82.

COMPUTER STORAGE AND RETRIEVAL OF POSITION-DEPENDENT DATA

Robert C. Groman

A data storage and retrieval scheme has been designed and implemented which provides cost effective and easy access to location-dependent, 'geophysical' data. The system is operational on a Digital Equipment Corporation VAX-11/780 computer. Values of measured and computed geophysical parameters, such as geomagnetic field, water depth and gravity field, are stored in the library system. In addition, information about the data, such as port stops, project name and funding agency are also saved. These data are available to a time sharing computer user, validated to use the software package, through a query language designed to interact with this data library. The data can be searched and retrieved both sequentially and geographically.

GEOLOGY

GEOLOGIC PROCESSES OF THE MID-OCEAN RIDGE AND THEIR RELATIONSHIP TO SULFIDE DEPOSITION

Robert D. Ballard and Jean Francheteau

Enough detailed data has been obtained along the axis of the Mid-Ocean Ridge to construct a kinematic model which attempts to describe observed variations in time, space, and spreading rate of volcanic, tectonic, and hydrothermal processes and their relationship to the deposition of massive sulfide deposits. The model draws upon submersible and towed camera mapping programs in the FAMOUS area of the Mid-Atlantic Ridge where the spreading rate is approximately 2 cm/yr. In addition, recent efforts along various segments of the East Pacific Rise and Galapagos Rift have the most profound impact on the model as they involve spreading rates ranging from 6.0 to 10.2 cm/yr where hydrothermal circulation and associated massive sulfide deposition is well developed.

THE RELATIONSHIP BETWEEN ACTIVE SULFIDE DEPOSITION AND THE AXIAL PROCESSES OF THE MID-OCEAN RIDGE

Robert D. Ballard and Jean Francheteau

A model is presented which attempts to explain the relationship between massive sulfide deposition and the axial processes of the Mid-Ocean Ridge. These processes include volcanism, tectonic fracturing, and hydrothermal circulation within the newly evolving oceanic crust. The model is based upon a series of detailed studies at slow to fast spreading centers along the Mid-Atlantic Ridge and East Pacific Rise using multi-narrow beam sonars, towed camera systems, and manned submersibles of both America and France. The model discusses observed variations in time, space, and spreading rate of these axial processes and attempts to predict where active massive sulfide deposition should be found.

THE EAST PACIFIC RISE NEAR 21°N, 13°N AND 20°S: INFERENCES FOR ALONG-STRIKE VARIABILITY OF AXIAL PROCESSES OF THE MID-OCEAN RIDGE

Jean Francheteau and
Robert D. Ballard

Data obtained along various segments of the Mid-Ocean Ridge (MOR) are used to construct an idealized model for crustal accretion. The model seeks to predict the topographic, volcanic, tectonic, and hydrothermal characteristics of any given spreading segment of the MOR as a function of distance away from the bounding transform faults. This model is based on a series of detailed mapping efforts carried out on segments of the MOR having a broad range of spreading rates between 2 and 16 cm/yr. This paper includes the results of the French SEARISE program carried out during the summer of 1980 aboard the N/O JEAN CHARCOT and two American cruises conducted in 1981 aboard the R/V MELVILLE.

INTENSE HYDROTHERMAL ACTIVITY AT THE AXIS OF THE EAST PACIFIC RISE NEAR 13°N: SUBMERSIBLE WITNESSES THE GROWTH OF SULFIDE CHIMNEY

R. Hekinian, J. Francheteau, V. Renard, R.D. Ballard, P. Choukroune, J.L. Cheminee, F. Albarede, J.F. Minster, J.C. Marty, J. Boulegue and J.L. Charlou

A submersible study of a fast spreading (12 cm/yr) Mid-Ocean Ridge segment led to the discovery of intense hydrothermal activity (East Pacific Rise near 12°50'N). Twenty-four sites with active vents and sixty inactive hydrothermal deposits were found within a narrow graben less than 300 m wide along a 20 km long segment of the ridge crest. The graben is floored with fresh basaltic sheet flows (including collapsed pits or lava lake structures). From both deep towed camera stations and manned submersible observations, it is estimated that the average spacing of the hydrothermal deposits along the rise axis (10-50 m in diameter) lies between 100 to 200 meters.

The hydrothermal deposits found in the central graben are believed to have formed rapidly (on the order of a few years). Detailed investigations of one active site have enabled us to witness the growth of an active chimney which increased its size by 40 cm in five days.

The most extensive hydrothermal deposits were found on an off-axis seamount located 4 km east of the ridge axis. The hydrothermal deposits found on both the ridge axis and on the seamount are similar in composition and consist essentially of zinc, copper and iron mineral phases.

I N S T R U M E N T A T I O N

A CCD CHIRP-Z FFT DOPPLER SIGNAL PROCESSOR FOR LASER VELOCIMETRY

Y.C. Agrawal

A charge-coupled Chirp-Z fast Fourier transform device which has been configured to obtain the frequency of peak spectral amplitude in signals from laser velocimeters is described for use in oceanographic and other low-laser power field applications where poor optical signals and frequent dropout are encountered. The resulting signal processor gives 8-bit resolution in the velocity word, with a cycle time of approximately 4 msec while scanning a spectral range of 0-135 kHz; higher frequency ranges are possible at proportionately faster spectral scan rates, up to a maximum of 2 MHz. Error estimates are presented which indicate 2-bit accuracy at signal-to-noise power ratio of -2 db. The combination of the processor together with a photodiode array detector described by the author (Agrawal and McCullough, 1981) radically simplifies the practice of laser velocimetry.

DIRECTIONAL LASER VELOCIMETRY WITHOUT FREQUENCY BIASING: PART II

Y.C. Agrawal and
J.B. Riley

In an earlier paper, Agrawal and McCullough (1981), it was demonstrated that a single laser beam focused at the point of measurement can be used to obtain both the magnitude and direction of local fluid velocity, without the use of beam splitting optics, or frequency biasing devices. Additionally, the photoelectric signal was shown to be a zero-mean sine wave suitable for counter-type processors. The method described in the above paper indicated the use of two offset detector arrays; the resulting photocurrents from the two arrays were correlated to give direction. In this paper, we describe how the method was implemented, using a self-scanning diode array. Detector sensitivity in the array is discussed and microchannel plate detectors are suggested for increased sensitivity.

BACKSCATTER LASER VELOCIMETER FOR ENERGETIC BOTTOM BOUNDARY LAYERS: THE OPTICAL SIGNAL

Y.C. Agrawal, W.E. Terry, Jr.
and A.J. Williams 3rd

The optical signal from a dual-beam backscatter laser Doppler velocimeter designed for oceanographic usage will be described both theoretically and experimentally. The instrument was constructed to simulate, in the laboratory, the strength and behavior of the optical signal as a function of mass concentration of natural particles in water – a subject of concern in the study of high energy benthic boundary layers. It has been found that with proper design, the predominant mode of signal degradation with increasing particle loading is caused primarily by increased shot noise due to signal attenuation alone. Secondly, the signal is observed to be in the single-scatterer mode at particle concentrations of up to 5 mg/l. Variations in observed signal-to-noise ratio will be described and compared with theoretical calculations.

CTD LOWERING MECHANICS

H.O. Berteaux and R.G. Walden

The many difficulties encountered in the deployment of CTD instrument packages, including the loss of an appreciable number of them, has prompted a comprehensive study of CTD instrument lowering mechanics. Conditions causing large cyclic cable tensions, shock loads or cable slack had to be investigated, modeled, and hopefully, measured in situ. The dynamic behavior of the instrument package needed to be assessed. Methods to improve its flight pattern as it travels through the water column and recommendations for safer and more efficient lowering procedures had to be formulated. This paper describes how the study was conducted and presents its salient findings and recommendations. In its conclusion the paper points out the limits of present CTD lowering systems and advocates that servo-controlled motion compensating winches be used in the future.

DEPLOYABLE PROCESSOR BASED INSTRUMENT DEVELOPMENT

Albert M. Bradley

In the Instrument Section of the Ocean Engineering Department at the Woods Hole Oceanographic Institution we concentrate on the development of autonomous deployable instruments for oceanographic research. The availability of the low power microprocessor has greatly increased the capability of our designs, but has changed our approach to the development of new instruments. This article describes an approach to the development of a microprocessor based instrument and presents a case for choosing the SAIL standard as a control and maintenance interface.

DIRECT OPTICAL ASSESSMENT OF MACROSCOPIC AGGREGATES IN THE DEEP OCEAN

Susumu Honjo, Kenneth W. Doherty,
Yogesh C. Agrawal and Vernon L. Asper

Large amorphous aggregates (LAA),
frequently cited as "marine snow", may
accelerate the flux of fine and dissolved
matter in the ocean by adsorption. LAA are
extremely fragile and this makes their
sampling with conventional towing and
casting impossible. In order to assess the
size and spatial distribution of macro-
scopic aggregates we have developed a
photographic surveillance system which can
be lowered to full ocean depth. The
system, based on the theory of light scat-
tering in water, uses a well-collimated
beam pointed downward from the vertical at
an angle of 45°. The beam is produced by
placing high-powered strobes at the back
focal plane of a Fresnel lens system.
Illuminated aggregates in the light slab
are photographed from a direction perpen-
dicular to the beam axis. The photographed
volume measures 106 x 156 x 40 cm thick.
The practical image resolution of this
instrument is about 0.2 mm. Macroscopic
aggregates were distributed throughout the
water column to 3521 m deep at all stations
along a 200 km transect of Monterey Bay.
The abundance of macroscopic aggregates
(greater than 0.5 mm) at these stations
ranged from roughly 10 aggregates/liter
near the surface to 2 aggregates/liter at
depth.

In press: Deep-Sea Research.

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WHOI Contribution No. 5036.

A VERSATILE MULTI-CHANNEL DATA ACQUISITION SYSTEM FOR SEISMIC AND ACOUSTIC APPLICATIONS

K.E. Prada, K. von der Heydt
and T.F. O'Brien

Versatility and reliability were key
factors in the design of a minicomputer
based digital data acquisition system.
Used both at sea and on the polar ice with
excellent results, it has been adapted to
tasks ranging from at-sea continuous
seismic profiling to low-level acoustic
transmission experiments.

Of particular interest is a floating
point amplifier utilizing a unique gain
switching method developed to permit
simultaneous sampling of multiple channels
up to a 1 kHz signal bandwidth. Other
features include continuous or intermittent
recording in a time demultiplexed format,

floating point normalization hardware,
sampling times traceable to absolute time,
and real-time video display of selected
data channels. The system can be used for
analysis and processing when not in the
acquisition mode.

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OCEAN ACOUSTICS

ACOUSTIC TOMOGRAPHY: A DEMONSTRATION

D. Behringer, T. Birdsall, M. Brown,
B. Cornuelle, R. Heinmiller, R. Knox,
K. Metzger, W. Munk, J. Spiesberger,
R. Spindel, D. Webb, P. Worcester
and C. Wunsch

Over the past decade oceanographers
have become increasingly aware of an
intense and compact ocean 'mesoscale' eddy
structure (the ocean weather) that is
superimposed on a generally sluggish
large-scale circulation (the ocean
climate). Traditional ship-based observing
systems are not adequate for monitoring the
ocean at mesoscale resolution. A 1981
experiment mapped the waters within a 300 x
300 km square south-west of Bermuda, using
a peripheral array of moored midwater
acoustic sources and receivers. The
variable acoustic travel times between all
source-receiver pairs were used to
construct the three-dimensional
(time-variable) eddy fields, using inverse
theory. Preliminary results from
inversions are consistent with the
shipborne and airborne surveys.

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WHOI Contribution No. 5237.

FLUCTUATIONS OF SOUND PROPAGATING VERTICALLY THROUGH THE OCEAN

Yves Desaubies

Fluctuations of sound propagating
vertically through the ocean is
considered. Expressions are derived for

the acoustic phase structure function and spectra. As an application, the errors incurred by systems based on travel time measurements (depth sounding and tracking systems) are estimated. They are found to be generally negligible.

NOTE ON FINE STRUCTURE MODELS IN UNDERWATER ACOUSTICS

Yves Desaubies

The quantity of central importance in wave propagation through a random medium is the time/space correlation of the medium, or, equivalently, the frequency wave number spectrum. In acoustics one needs the sound speed fluctuations spectrum, which is simply proportional to the temperature spectrum. The question is then which spectrum to use. The only model available for internal waves is that of Garrett and Munk (GM); since that empirical model is based in part on temperature data, and since such data include whatever processes occur in the ocean (non-linear advection, fine structure, sheets and layers, etc.) one might think that no corrections are necessary and that the GM spectrum can be directly incorporated, without modifications into the acoustic calculations. This is not the case. The GM model is not just a curve fitting to temperature spectra, but is a self consistent model incorporating through linear relations velocity spectra and various cross-spectra. The GM spectrum must then be interpreted as a displacement spectrum from which the sound speed spectrum must be deduced.

This transformation is part of the object of the two studies discussed here. While the two papers convincingly demonstrate that some form of fine structure contamination can have a significant effect on the acoustic amplitude fluctuations, the models, being somewhat ad hoc, do not necessarily reflect the physics of the internal wave field, and the results can be viewed only as qualitatively correct.

MEASUREMENTS OF SEASONAL THERMOCLINE DEVELOPMENT AND GULF STREAM MEANDERING USING LONG RANGE ACOUSTIC TRANSMISSIONS

J.L. Spiesberger, T.G. Birdsall, K. Metzger, R.A. Knox, C.W. Spofford and R.C. Spindel

Phase-coded signals with 60 ms resolution were transmitted from acoustic sources at ~2000 m depth in the Sargasso Sea to three bottom-mounted receivers designated as West, East, and North stations at ranges between ~1000 and ~2000 km. The transmission paths to West and East stations were entirely in the Sargasso Sea. The path to North station crossed the Gulf Stream and so traversed one of the most time and range-dependent ray traces. Travel times at West station clearly change in response to the warming of the seasonal thermocline from spring to summer. The travel time change agrees with predictions. Travel time changes at North station primarily respond to the north-south meandering of the Gulf Stream.

INSTRUMENTATION FOR OCEAN ACOUSTIC TOMOGRAPHY

R.C. Spindel, P.F. Worcester, D.C. Webb, P.R. Boutin, K.R. Peal and A.M. Bradley

A test ocean acoustic tomography experiment was conducted in the southern North Atlantic during 1981. Travel time variations of pulse-like signals transmitted between moored acoustic sources and receivers separated by hundreds of kilometers were used to image the intervening sound speed field. Intelligent sources, receivers, mooring positioning monitoring systems and precision time-keeping devices were developed specifically for this application. In this paper we describe the design of these instruments and we present examples of their use in the tomography experiment to show satisfactory overall system performance.

PHYSICAL OCEANOGRAPHY

A NOTE ON THE HEAT BALANCE OF THE MEDITERRANEAN AND RED SEAS

A.F. Bunker, H. Charnock
and R.A. Goldsmith

The Mediterranean and Red Seas are used as test volumes in an attempt to assess the accuracy of estimates of climatological air-sea fluxes calculated using meteorological observations from merchant ships.

Although the radiative flux estimates are subject to error, especially those of net longwave radiation, it is difficult to obtain an acceptable heat balance if the evaporative fluxes are calculated using values for the exchange coefficient now widely accepted by specialists in near-surface turbulent transport. Larger coefficients seem to be needed: they may be a compensation for ships' avoidance of high winds and for systematic errors of observation.

STATISTICS OF RICHARDSON NUMBER AND OF INSTABILITY IN OCEANIC INTERNAL WAVES

Yves Desaubies and Woollcott K. Smith

The probability density function of Richardson number in a gaussian internal wave field is derived. It is found to compare well with available data. The p.d.f. depends on only parameter λ, the r.m.s. strain in the field, which is very weakly dependent on depth if at all. The probability $Ri < 0.25$ is a very sensitive function of λ, which is about $\lambda \simeq 0.5$ in the ocean. Numerical simulations of vertical profiles $Ri(z)$ are calculated based on a set of stochastic differential equations. The statistics of the vertical distributions of regions where $Ri < 0.25$ is investigated and a simplified mixing model based on the stochastic differential equations is derived. We conclude that shear instability is a significant factor in the dissipation of internal waves.

SHORT PERIOD INTERNAL WAVES IN MASSACHUSETTS BAY: DEVELOPMENT, DECAY AND ASSOCIATED MIXING PROCESSES

Marshall H. Orr

High frequency internal wave packets are generated on the western side of Stellwagen Bank (30 m depth) and propagate southwesterly through Massachusetts Bay (85 m depth). These internal wave packets are formed when a lee wave, generated by an easterly ebb tide flow across the bank, propagates westward as the ebb tide slacks and encounters the western bank edge. Lee waves, high frequency internal waves, and a variety of associated mixing processes have been obtained with a high frequency acoustic system (200 kHz) operated in a monostatic pulsed mode. This data set has been combined with visual observations of the position of the internal wave surface expression, expendable bathythermograph (XBT) and conductivity/temperature/depth (CTD) data to provide a detailed view of the temporal and spatial development of the phenomena. The CTD data support the contention that acoustic backscattering from temperature fluctuations associated with regions of high shear has been detected. The combined visual observation and acoustic records suggest that some surface capillary wave zones associated with internal waves are the result of high shear zones being brought close to the water surface by the internal wave and are not induced by wind, as often maintained in the literature.

DETECTION OF HYDRAULIC JUMPS, INTERNAL WAVES, LEE WAVES, AND SHEAR INSTABILITIES IN THE VICINITY OF THE HEAD OF HUDSON CANYON

Marshall H. Orr and Frederick R. Hess

Shear instabilities, hydraulic jumps, short-period internal waves and mode 1 and 2 lee waves have been identified in acoustic records obtained near the Hudson Canyon head. These phenomena are thought to be caused by flow across the canyon sill perpendicular to the canyon axis. During the experiment, the northeastern wall of the canyon was found to be an area of considerable flow variability, while the area of the southwestern wall did not

display as much flow variability. The acoustics data indicate that, in addition to the previously suggested fluid processes (i.e., focused internal waves, tidal flow, and the passage of severe storms), flow across the canyon sill perpendicular to the canyon axis creates a regime which could allow particles to settle into the canyon and could allow mixing to develop between the shelf water flowing over the sill and water contained in the canyon.

S I G N A L   A N D   A R R A Y
P R O C E S S I N G

COMPOSITE BOUND ON THE ATTAINABLE MEAN SQUARE ERROR IN PASSIVE TIME-DELAY ESTIMATION FROM AMBIGUITY PRONE SIGNALS

Ehud Weinstein

The location of a radiating source can be determined by measuring the relative time-delay of its signal wavefront to several spatially separated receivers. A new technique is presented to investigate the performance of time-delay measurement schemes based on a modified version of the Ziv-Zakai lower bound. This technique is shown to yield a tight bound on the attainable mean square measurement error for any pre-specified signal-to-noise ratio conditions.

MEASUREMENTS OF THE DIFFERENTIAL DOPPLER SHIFT

Ehud Weinstein

Doppler shifts between narrow-band signals observed at one or more pairs of receivers and originated from a remote source of radiation are useful for estimating source location and track. This paper deals with an instrumentationally attractive approach of estimating

differential Doppler shifts by making center frequency measurements at each receiver output and subtracting them in a pairwise fashion. For low in-band signal-to-noise ratio conditions, center frequency measurements at different receiver outputs are weakly correlated. In this mode of operation, therefore, the mean-square error in the differential Doppler estimate equals the pairwise sum of the mean-square errors in each of the center frequency measurement. For high signal-to-noise ratio conditions, the various center frequency estimates are strongly correlated. In this mode of operation, the accuracy of the resulting differential Doppler estimate improves with the first power of the signal-to-noise ratio, even though the accuracy of each center frequency estimate approaches an absolute bound independent of the noise spectrum.

The optimal (minimum mean-square error) differential Doppler shift estimate is obtained by simultaneous processing of the receiver outputs jointly. Comparison between the former (indirect) and the latter (direct) estimation techniques yields some interesting insights: the accuracy of the direct estimation procedure is proportional to T^{-3} where T is the observation period. It is basically a coherent procedure. Center frequency measurement and the differential Doppler shift estimate derived from it are basically incoherent procedures and obey the well known T^{-1} dependence. Under high signal-to-noise ratio conditions, the estimation error in both methods decreases with the first power of the signal-to-noise ratio. Under low signal-to-noise ratio conditions, the accuracy of the suboptimal indirect method is inferior to the optimal direct method by a factor proportional to the inverse first power of the individual signal-to-noise ratio.

ON THE USE OF FOCUSED HORIZONTAL ARRAYS AS MODE SEPARATION AND SOURCE LOCATION DEVICES IN OCEAN ACOUSTICS

James F. Lynch

It is shown that one can perform mode separation and source location using a focused horizontal array by utilizing the fact that the system response is greatest to a source located at or near the focal

point. This mode separation/source location scheme is discussed for four different physical situations: (1) a motionless point cw source in a range invariant environment, (2) a motionless point cw source in a range varying environment, (3) a motionless point broadband source in a range invariant environment, and (4) a moving cw source in a range invariant waveguide environment. Two types of (horizontal) arrays are treated, the line array and the convex circularly curved array.

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WHOI Contribution No. 5316.

SOME SIMPLE EXPRESSIONS FOR THE BEAMFORMING PROPERTIES OF FOCUSED HIGH RESOLUTION CIRCULAR ARRAYS, WITH APPLICATIONS TO REFOCUSING SYSTEMS

James F. Lynch

Some simple analytical expressions for two important optical characteristics of focused high resolution circular arrays are derived, specifically those for beam patterns and depth of field. The expressions generated, in addition to providing simple estimational tools for array design purposes, also lend themselves to straightforward interpretation in terms of the Fourier (farfield) and Fresnel (nearfield) kernels. Applications to refocusing arrays are discussed, as well as similarities and differences between such (sonar oriented) systems and radar and optical systems.

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WHOI Contribution No. 5281.

STABILITY ANALYSIS OF LMS ADAPTIVE FILTERS

Ehud Weinstein

An extensive stability analysis of the LMS (Least Mean Squares) adaptive scheme is presented and exact analytical expression for the steady state error variance and the performance degradation due to weight vector misadjustment are derived. It is found that the loop gain μ which controls

the rate of adaptation must be restricted to an interval significantly smaller than the domain commonly stated in the literature, in order to ensure the convergence of the algorithm to the optimal (Wiener) solution within a finite variance. The outcome result of this paper therefore places fundamental limitations on the performance and rate of convergence of the LMS adaptive algorithm.

Supported by: ONR Contract N00014-77-C-0196.

SUBMERSIBLES

WEIGHT AND STABILITY OF DSRV ALVIN, 1981-82

Arnold G. Sharp

Weight and stability computations are presented for the research submersible ALVIN for the years 1981-82. Programmed computations were performed for major ALVIN subassemblies as well as for the entire vehicle in the normal surface and normal submerged conditions. During the most recent maintenance period in Woods Hole in early 1981 structural changes to ALVIN were minimal. Therefore it was expected there would be only slight changes in vehicle weight and stability. Comparison of present calculations with those of 1980 showed this to be true.

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WHOI Technical Memorandum No. 4-82.

UNDERWATER EXPLOSIONS

MORTALITY OF FISH SUBJECTED TO EXPLOSIVE SHOCK AS APPLIED TO OIL WELL SEVERENCE ON GEORGES BANK

L. Baxter, II, E.E. Hays, G.R. Hampson and R.H. Backus

A very extensive bibliography of papers on underwater explosions and their effects on marine life has been collected and summarized. When exposed to blast effects, vertebrates with swim bladders or lungs that contain gas are at least an order of magnitude more sensitive than other life. Regression analysis of several different experiments on explosive damage to fish has been combined with reports of fish

concentrations and explosives used in oil
well severance in order to estimate the
probable extent of damage to fish
populations from a limited number of
severance explosions. Damage per explosion
should not be significant and is probably
considerably less than that caused by a one
hour tow of a bottom trawl net.

A HIGH QUALITY LOW COST RECEIVER
FOR MILITARY SONOBUOYS

Donald E. Koelsch and Frederick R. Hess

Radio sonobuoys have demonstrated their
utility as an inexpensive replacement for a
second ship in a variety of marine seismic
reflection and refraction operations.
Their use provides a cost-effective method
for the determination of crustal velocity
structures, and particularly that of the
shallow most sedimentary strata. Military
sonobuoys, most generally of the SSQ-41A,B
family, are readily available to the
academic community. Unfortunately,
appropriate receivers are not so readily
available. This note describes a cost
effective method of configuring a high
quality sonobouy receiver using simple
frequency converters and an FM receiver.

DEPARTMENT OF PHYSICAL OCEANOGRAPHY

Nicholas P. Fofonoff, Department Chairman

PHYSICAL OCEANOGRAPHY

B O T T O M   T O P O G R A P H Y

LOW FREQUENCY FREE WAVE AND WIND-DRIVEN MOTIONS OVER A SUBMARINE BANK

Kenneth H. Brink

This study attempts to isolate the physics peculiar to a submarine bank. The particular model is barotropic and contains an infinitely long straight bank within an unbounded ocean basin. The low frequency free wave solutions consist of two infinite sets of modes, analogous to barotropic continental shelf waves, one set trapped to each side of the bank. In addition, a severely distorted double Kelvin wave is associated with the net depth difference across the bank. Inclusion of bottom friction representative of Georges Bank suggests that only one free wave (westward propagating on the south side) will have a sufficiently long decay time to be likely to be observed in nature. The spatial variation in local spindown time also causes the lines of constant wave phase to be no longer perpendicular to the isobaths. Steady, forced motions are considered for winds which vary slowly in the alongbank direction. When the Ekman scale depth is the same order as the minimal depth over the bank, the primary driving mechanism is related to the disruption of surface Ekman transport by bottom friction. Alongbank wind stress is shown to be a fairly ineffective driving agent, while crossbank winds drive geostrophic currents relatively effectively. Also, since the crossbank winds vary in the alongbank direction, the resulting stress curl drives motions in the entire ocean. These large scale currents are closed in boundary layers on the outer edges of the bank, thus isolating the inner bank from deep ocean influence.

SOME EFFECTS OF STRATIFICATION ON LONG TRENCH WAVES

Kenneth H. Brink

The characteristics of long, gravest mode trench waves in the presence of realistic stratification are investigated. Two examples are computed, representing cases with widely differing importance of baroclinic effects. In both cases, the wave-related alongshore velocity structure becomes noticeably bottom intensified, but much less so for the high latitude (smaller internal Rossby radius of deformation) Aleutian trench example than for the low latitude (larger Rossby radius) Peru trench example. Some consequences of the bottom trapping are then discussed.

INTERACTION OF THE ANTARCTIC CIRCUMPOLAR CURRENT WITH BOTTOM TOPOGRAPHY: AN INVESTIGATION USING SATELLITE ALTIMETRY

Marie T. Colton and Robert R. P. Chase

Theoretical studies on the interaction of a zonal current with a zonal ridge, an isolated bump, and a meridional ridge compare favorably with hydrographic observations within the eastward flowing Antarctic Circumpolar Current where it flows over similar topographic features. However, the existing hydrographic data are insufficient for examining the temporal stability and kinematic behavior of the resulting mesoscale structures. In this study, some of these transient features have been compared with patterns in sea surface variability, derived from collinear satellite altimetric data. When these features occurred near the crossing point of two satellite ground-traces, it was possible to characterize their length scales, dynamic height relief, and translational and surface geostrophic velocities.

GROWTH RATES OF A TOPOGRAPHIC INSTABILITY

Stephen P. Meacham

Growth rates for a linear model of a topographically-induced shear instability described by Pedlosky (J. Phys. Oceanogr., 10, 1877-1880, 1980) are computed numerically over a limited range of model parameters and are found to be consistent with the perturbation theory given by Pedlosky. When values consistent with

oceanographic data obtained near Site D are assigned to the model parameters, the growth rates obtained are found to be relatively small.

COASTAL DYNAMICS

THE NEAR-SURFACE DYNAMICS OF COASTAL UPWELLING

Kenneth H. Brink

An attempt is made to examine some observational and theoretical aspects of upper ocean dynamics in regions of strong coastal upwelling. "Upper ocean" is roughly defined as about the upper 10-30 m of the water column for most systems. First, the basic surface Ekman and mixed layers are discussed, including some of the modifications due to upwelling. Next, coastal upwelling fronts and their associated circulation are treated. Finally, areas of strongly three-dimensional upwelling are classified and discussed. Horizontal advection of heat and momentum appear to be generally important for the near-surface dynamics of coastal upwelling, and these phenomena make realistic theoretical treatments especially difficult.

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A NOTE ON THE USEFULNESS OF TWO-LAYER, SHELF WAVE MODELS

David C. Chapman

Some past studies of continental shelf waves utilize the two-layer Laplacian model (in which Laplace's tidal equations on an f-plane are assumed to describe the motion of each layer). This note compares the dispersion properties of shelf waves predicted by the two-layer Laplacian model with those predicted by the more realistic geophysical model (in which continuous stratification is retained by taking the Väisälä frequency N much greater than the inertial frequency f) over a step shelf. As suggested by Chapman (Dyn. Atmos. Oceans, 7, 1, 1-16, 1982), the two-layer Laplacian model qualitatively misrepresents the dispersion properties of shelf waves in the geophysical model. The existence of "kissing" modes as reported by Allen (J. Phys. Oceanogr., 5, 300-325, 1975) and Wang (J. Phys. Oceanogr., 5, 326-333, 1975) appears to be an unrealistic artifact of the two-layer Laplacian model. However, the two models predict some qualitatively similar behavior in the long wave limit where the waves are nearly nondispersive. At low latitudes ($f/N \to 0$) where the internal Rossby radius is large, the lowest mode in each model is a deep-sea baroclinic Kelvin wave. At high latitudes (small internal Rossby radius), the lowest mode in each model becomes a step-trapped shelf wave and the solutions are separated into those trapped either at the step or at the coast.

ON THE INFLUENCE OF STRATIFICATION AND CONTINENTAL SHELF AND SLOPE TOPOGRAPHY ON THE DISPERSION OF SUBINERTIAL COASTALLY-TRAPPED WAVES

David C. Chapman

The behavior of subinertial, coastally-trapped free waves in a continuously stratified ocean is examined using a two-slope topography in which the continental shelf and slope are each represented by a single uniform slope. Surface-intensified stratification is assumed of the form $N^2 e^{\beta z}$, where N is the Väisälä frequency at the surface ($z = 0$) and β the vertical decay scale normalized by the deep-sea depth. The continental slope is typically assumed to be steeper than the shelf. Two qualitatively different types of dispersive behavior are distinguished. When $(N/f)a_2 > \overline{K}$, where f is the Coriolis parameter, a_2 the bottom slope of the continental slope, and $\overline{K}$ a function of topography and β, then free waves may occur at any subinertial frequency, and each dispersion curve rises to f at some finite alongshore wavenumber (as in the case of baroclinic Kelvin waves). If $(N/f)a_2 < \overline{K}$, then all the free wave dispersion curves are limited to frequencies below some subinertial maximum, but are unlimited in wavenumber.

With uniform stratification, the function $\overline{K}$ equals 1 independent of the shelf width or shelf-break depth. Furthermore, for realistic shelf-break depths, $\overline{K}$ is only a weak function of topography and β, and $\overline{K}$ is less than 2 even

for large β, suggesting that the continental slope and the stratification there almost completely determine whether or not the dispersion curves ultimately go to f. Because realistic values of $(N/f)a_2$ are typically of order one or greater, stratification effects may be crucial for accurately modeling coastally-trapped wave behavior, especially when short waves are important as in scattering or resonant interaction calculations.

Long, low frequency waves are primarily affected by the shelf width and the shelf stratification. If the offshore baroclinic length scale is less than the shelf width, then the long wave phase speed may be accurately predicted by barotropic models independent of whether or not the dispersion curve ultimately goes to f.

THE MIDDLE ATLANTIC BIGHT COLD POOL: EVOLUTION OF THE TEMPERATURE STRUCTURE DURING SUMMER 1979

Robert W. Houghton, Ronald J. Schlitz, Robert C. Beardsley, Bradford Butman and J. Lockwood Chamberlin

Temperature data spanning the entire Middle Atlantic Bight (MAB) during 1979 are used to study the structure and evolution of the cold pool. The Nantucket Shoals and New England Shelf appear to be the source of the coldest water found in the MAB in late winter. During the spring and summer, water within the cold pool in the New York Bight north of Hudson Canyon remains colder than any shelf water either to the northeast or southwest. Thus the coldest cold pool water persists there as a remnant of winter-cooled water rather than being replenished by a colder upstream source, and south of Hudson Canyon, cold-pool temperatures decrease in June and July as colder water from upstream is advected southwestward along the coast. Both temperature data and direct current measurements suggest that the mean alongshore current has a minimum between Nantucket Shoals and Hudson Canyon. The alongshore variation of shelf topography appears to be responsible for the spatial variation in both the alongshore drift speed and the thermal structure of the cold pool.

AN OBSERVATION OF FRONTAL WAVE DEVELOPMENT ON A SHELF-SLOPE/WARM CORE RING FRONT NEAR THE SHELF BREAK SOUTH OF NEW ENGLAND

Steven R. Ramp, Robert C. Beardsley and Richard Legeckis

Small-scale waves have been observed near $40°N$, $68°30'W$ in specially enhanced satellite imagery of a strong temperature front formed in May 1979 between the shelf/slope water front and warm core ring 79-B. These frontal waves had a wavelength of 23 ± 4 km, an eastward propagation speed of 32 ± 4 km/d, and a growth rate (e-folding time) of roughly 17.5 hours (12 to 19 hours). This satellite data plus current velocity and hydrographical data gathered from the Nantucket Shoals Flux Experiment (NSFE79) allow comparison of the observed growth rate with theoretical predictions based on the assumption of a Margules front and the instability model of Orlanski (J. Atmos. Sci., 25, 178-200, 1968). This comparison suggests that the observed frontal waves were due primarily to horizontal shear instability and derived their energy from the mean flow structure across the front in the presence of ring 79-B.

SELF-ADVECTION OF DENSITY PERTURBATIONS ON A SLOPING CONTINENTAL SHELF

Ping-Tung Shaw and Gabriel T. Csanady

Bottom water movement on the continental shelf is modeled by the nonlinear interaction between longshore bottom geostrophic flow and the density field. Bottom geostrophic velocity, subject to linear steady momentum equations with linear bottom friction, can be generated by long-isobath density variations over a sloping bottom. At the same time, the density field is slowly advected by the velocity field. Away from the boundary layers, the interplay is

governed by Burgers' equation, which shows the formation and self-propulsion of strong density gradients along an isobath. The direction of propagation of a dense water blob is to have shallow water on the right (left-) hand side facing downstream in the Northern (Southern) Hemisphere. The propagation of a light water blob is opposite to that of a dense water blob.

The problem is further investigated by solving the governing equations numerically. Under forcing by localized surface cooling, the flow in the mid-shelf region shows the characteristics of the solution of Burgers' equation. A coastal buoyancy source generates a shore-hugging plume, slowly moving along the coast in the direction of Kelvin wave propagation. The flow associated with coastal dense water discharge has different characteristics: the dense water moves away from the coast initially. The accumulation of dense water on the mid-shelf then invokes the same self-advection process as found for surface cooling.

The theory sheds light on bottom movements in the Adriatic Sea, the Antarctic Continent and the Middle Atlantic Bight. It also describes the dispersion of river water and dense water outflow on the shelf. The model results agree qualitatively with the observed distribution of bottom water and give correct order of magnitude estimates for the propagation speed of density perturbations.

I N T E R N A L   W A V E S

OBSERVATIONS ON THE ENERGY BALANCE OF INTERNAL WAVES DURING JASIN

Melbourne G. Briscoe

Depth integrated horizontal kinetic energy (hke) in the frequency band 0.1-4 cycles per hour is used to estimate the time variation at one site of internal wave energy over a 40-day period during JASIN 1978. The hke smoothed over 3 days varies from 400 to 1500 J m^{-2}. The canonical Garrett-Munk total energy of 3800 J m^{-2} would provide about 1400 J m^{-2} of hke in this high-frequency band; a scaled down estimate based on local mean buoyancy frequency and water depth suggests 450 J m^{-2}.

The first part of the record (1 to about 16 August) slowly grows then decays in energy to the record minimum at rates between 0.6 and -1 mW m^{-2}, followed by about 11 days of sporadic growth and decay at rates between 3 and -0.8 mW m^{-2} to the record maximum, followed by a week of fast decay at rates between -2 and -1 mW m^{-2}.

A speculative balance of possible energy sources, sinks, and advection/propagation is discussed. The tentative conclusion is that horizontal shears and wind stress fluctuations are the principal energy sources, the latter possibly via interacting surface waves, and that loss of energy from the internal wave continuum to the near-inertial band may be a major sink of hke. A surprising heuristic correspondence is shown between the amplitude of the local surface wave field, and the internal wave energy eleven days later.

DETECTION OF MASSACHUSETTS BAY INTERNAL WAVES BY THE SYNTHETIC APERTURE RADAR (SAR) ON SEASAT

Richard P. Trask and Melbourne G. Briscoe

We have examined all eight SEASAT passes over Massachusetts Bay that yielded synthetic aperture radar (SAR) imagery. Four of the passes showed banded surface features that suggested a group of internal waves propagating southwestward from Stellwagen Bank. Comparison of the positions of the SAR features with predictions of internal wave locations derived from earlier in-situ work at Massachusetts Bay confirms that the SAR features are indeed rough and smooth bands of water caused by a propagating packet of internal waves. (The packet is caused by tidal currents interacting with the stratification over and the topography of Stellwagen Bank.) Even the four passes that do not show internal waves are consistent with the above conclusions since the predicted packet positions occur outside the region covered by those four passes. These comparisons are presented to show that the SEASAT SAR is indeed capable of detecting internal waves in Massachusetts Bay, even though these waves are considerably less intense than in some other reported areas of the world.

SEASAT: The satellite launched by NASA for remote sensing of oceanic phenomena.

LABORATORY MODELS

A NOTE ON NONLINEAR INITIAL-VALUE EXPERIMENTS INVOLVING SHALLOW FLOW OVER OBSTACLES

Lawrence J. Pratt

The mechanism by which an obstacle partially blocks a shallow, homogeneous flow is explored numerically. It is demonstrated that within a certain parameter space, the blocking tendency depends not only on the height b_0 of the obstacle but on the history of the flow as well. The implied hysteresis confirms behavior predicted by Baines and Davies (In: Orographic Effects in Planetary Flows, GARP Pub. Ser. No. 23, p. 239, 1980). It is further shown that the hysteresis is associated with a nonuniqueness in steady solutions which is, in turn, attributed to the existence of stationary bores upstream of the obstacle.

ON INERTIAL FLOW OVER TOPOGRAPHY PART 1. SEMIGEOSTROPHIC ADJUSTMENT TO AN OBSTACLE

Lawrence J. Pratt

The nonlinear, time-dependent adjustment of a homogeneous, rotating-channel flow to the sudden obtrusion of an obstacle is studied. Solutions are obtained using a Lax-Wendroff numerical scheme which allows rotating breaking bores and jumps to form and be maintained. The flow upstream of the obstacle is found to be completely blocked, partially blocked (and hydraulically controlled), or unobstructed depending upon the height of the obstacle. Partial blockage is accomplished through the excitation of a combination of nonlinear Kelvin waves, some of which

steepen into interfacial shocks and one of which spreads as a rarefaction wave. The shocks are surrounded by dispersive regions of Rossby deformation scale and the potential vorticity of passing fluid is altered at a rate proportional to the differential rate of energy dissipation along the line of breakage. For the special case of initially uniform potential vorticity jump conditions and Riemann invariants describing the nonlinear waves are derived and the asymptotic state is found as a function of the initial conditions.

LARGE SCALE OCEANIC HEAT AND WATER PROPERTIES

EIGHTEEN DEGREE WATER VARIABILITY

Lynne D. Talley and Mary E. Raymer

The Eighteen Degree Water of the western North Atlantic is formed by deep convection in winter. The circulation and changing properties of Eighteen Degree Water are studied using hydrographic data from a long time series at the Panulirus station (32°10'N, 64°30'W) and from the Gulf Stream '60 experiment. Due to its relative vertical homogeneity, which persists year-round, the Eighteen Degree Water can be identified by its low potential vorticity $(f/\rho)(\partial\rho/\partial z)$. The Eighteen Degree Water is formed in an east-west band of varying characteristics offshore of the Gulf Stream. The Eighteen Degree Water formed at the eastern end of the subtropical gyre recirculates westward past the Panulirus station. Renewal of Eighteen Degree Water occurred regularly from 1954 to 1971, ceased from 1972 to 1975, and began again after 1975. The properties (18°C, 36.5°/oo) of Eighteen Degree Water seen at the Panulirus station were nearly uniform from 1954 to 1964. There was a shift in properties in 1964 and by 1972 the Eighteen Degree Water properties were 17.1°C, 36.4°/oo. The new Eighteen Degree Water formed after 1975 had nearly the same characteristics as that of 1954.

The density, potential temperature, salinity and the temperature-salinity relation of the entire upper water column at the Panulirus station changed at the

same time as the Eighteen Degree Water properties. The upper water column was denser and colder from 1964 to 1975 than from 1954 to 1964 and after 1975.

OCEAN   CIRCULATION

ESTIMATES OF MASS, MOMENTUM, AND KINETIC ENERGY FLUXES OF THE GULF STREAM

Nick P. Fofonoff and Melinda M. Hall

Mass, momentum, and kinetic energy fluxes in the Gulf Stream have been estimated from hydrographic data taken by Fuglister in the Gulf Stream '60 project; the data covers the Stream as it flows eastward, south of Georges Bank to the Grand Banks. The results are compared to a two-layer, constant potential vorticity inertial jet model and reasonable agreement is found. Error estimates based on the model and the data indicate errors of up to about 30 percent for mass and momentum and 50 percent for kinetic energy fluxes. All three fluxes exhibit considerable downstream divergence; the dynamical implications of these divergences for the region are assessed, and the importance of nonlinear effects in the Stream is discussed. It is suggested that there may be a significant conversion of kinetic to potential energy and that this mechanism ought not to be excluded a priori by examining primarily linear models of the Stream.

HYDRAULIC CONTROL AND FLOW SEPARATION IN A MULTI-LAYERED FLUID WITH APPLICATIONS TO THE VEMA CHANNEL

Nelson G. Hogg

Observations from a recent field experiment in the Vema Channel are briefly described. These show a remarkable change in the configuration of isopycnal surfaces within the channel and the development of thick, nearly homogeneous regions near the bottom which are capped by sharp vertical gradients. Contrary to previous speculation that these "bottom boundary layers" result from enhanced vertical mixing, a dynamical mechanism is explored. This involves the hydraulic adjustment of an inertial, semigeostrophic flow to the channel geometry.

First a two active layer flow in a rectangular geometry is studied to show that internal flow separation can occur when the flow is accelerated sufficiently by narrowing the channel. Almost always this separation accompanies hydraulic control: the slowest upstream moving Kelvin wave is stopped and upstream and downstream states are not symmetric with respect to the channel width. A three active layer flow with a variable bottom profile is then presented as a more accurate model of the Vema Channel. The crucial geometrical ingredient appears to be the growth of a plateau on the eastern side of the channel: this laterally confines the deepest layer but is more of a sill effect on the upper layers. Many of the observed features of the flow are explained by this model including the changing layer shapes, flow separation, and the reverse flow found above the plateau.

A major disagreement is that the flow in the farthest downstream section does not appear to be separated but more closely resembles that at the entrance. It is suggested that upstream of this last section a hydraulic jump occurs, returning the flow to a subcritical state of lower energy. Consistent with this idea the potential energy of the deeper layers increases and the wave perturbation amplitudes have the correct tendency.

A NOTE ON THE DEEP CIRCULATION OF THE WESTERN NORTH ATLANTIC: ITS NATURE AND CAUSES

Nelson G. Hogg

Based on presently available long-term moored current measurements, the abyssal circulation in the western North Atlantic is hypothesized to have two components. One is above the 4000 m isobath and transports about 10×10^6 m^3/sec of water along the whole of the Continental Rise and Slope. This appears to be the classical thermohaline Deep Western Boundary Current. The second component is farther offshore and takes the form of two gyres each recirculating as much as

40×10^6 m^3/sec with little direct influence of the New England Seamounts although in their neighborhood. This circulation scheme is in major disagreement with either the one of Worthington (The Johns Hopkins Oceanographic Series, 6, 110 pp., 1976) or that of Wunsch and Grant (Prog. Oceanogr., 11, 1-59, 1982), principally in the nature of the recirculating gyres. The southernmost of the recirculating gyres has been suggested by Schmitz (J. Mar. Res., 35(1), 21-28, 1977).

Calculations based on POLYMODE Array 2 current meter data indicate that both lateral and vertical eddy momentum fluxes are important in driving these gyres. It is suggested that the principal role played by the New England Seamounts is to intensify the eddy field, thereby inducing a divergence of the Reynolds stress.

THE BAROCLINIC STABILITY OF THE ATLANTIC NORTH EQUATORIAL CURRENT

Thomas Keffer

POLYMODE Array III, Cluster C, was a collection of four current meter moorings that were placed in the Atlantic North Equatorial Current for one year in May 1978. They were designed to look for indications of baroclinic instability such as downgradient eddy heat fluxes and upward phase propagation. However, Fu, Keffer, Niiler and Wunsch (J. Mar. Res., 40, 3, 809-848, 1982) and Keffer (J. Phys. Oceanogr., in press, 1983) find that the eddy heat fluxes tended to be more across gradient and sometimes even upgradient. They also find only slight indications of upward phase propagation.

In this study, the linear stability model of Gill, Green and Simmons (Deep-Sea Res., 21, 499-528, 1974) is applied to determine the expected heat fluxes, and the modal shapes and scales due to linear amplification. It appears that the expected fluxes should be detectable. Modal shapes are similar to the observed shapes but the fastest growing mode is only about half the size of the observed correlation scale.

Although these discrepancies could be explained by simple statistical variability, the supercriticality of the mean flow, the large observed length scales, and the relatively high eddy energies all suggest that this is a region

of fully developed finite-amplitude flow. Recent numerical model results of Holland tend to support this hypothesis.

NORTH ATLANTIC POTENTIAL VORTICITY AND ITS RELATION TO THE GENERAL CIRCULATION

Scott E. McDowell, Peter B. Rhines and Thomas Keffer

Maps and sections of the large-scale North Atlantic potential vorticity, q, are presented. q is $f d\rho/dz$, where f is the Coriolis frequency, ρ the potential density and z the vertical coordinate. They bear on the general circulation, and on geostrophic waves, instability and turbulence in many ways; both Eulerian and Lagrangian mean circulations proceed along isostrophes, q = const. in a zero-dissipation region. In a resting fluid q varies simply as the sine of the latitude, but we show here that the wind-driven circulation reshapes the q-field, creating 'bowls' and 'plateaus' which allow the flow to cross latitude circles. The implied nature of the western boundary current is very different than in classical frictional theory. The maps show a region of uniform potential vorticity in the wind gyre (σ_θ = 26.5-27.0) which fills the ocean between 15°N-37°N and 20°W-80°W. Such regions were prominent features of a circulation theory of Rhines and Young (J. Mar. Res., Suppl. to 40, 559-596, 1982 and J. Fluid Mech., 122, 347-367, 1982). At deeper levels, and close to surface outcrops of the density layers, the isostrophes are 'open', extending over a vast latitude range in mid-ocean. They provide flow paths, for example, which connect the Labrador Sea and the subtropical deep ocean without the need of dissipation of potential vorticity.

The maps of q show where the North Atlantic is susceptible to baroclinic instability. The generalized Rayleigh criterion for instability is satisfied in a large region south of the center of the wind gyre, between 10°N and 32°N. This supports the idea that eddy production is a strong feature of the subtropical mid-ocean regions.

AN OBJECTIVE ANALYSIS OF THE POLYMODE LOCAL DYNAMICS EXPERIMENT
I. GENERAL FORMALISM

James C. McWilliams, W. Brechner Owens and Bach-Lien Hua

A formalism is presented for making optimal estimates of a variety of mesoscale quantities--streamfunction, potential vorticity, and both linear and nonlinear terms in the dynamical balance equations for heat and potential vorticity--based upon measurements made during the POLYMODE Local Dynamics Experiment (LDE). The formalism is based upon the dynamical assumptions of geostrophic and hydrostatic balance. A hierarchy of statistical assumptions is considered, in order that estimators can be selected which are an appropriate compromise between accuracy and simplicity. This formalism is to be used in future estimates from the LDE data.

HORIZONTAL ADVECTION OF TEMPERATURE IN THE DRAKE PASSAGE

Alberto R. Piola

Low frequency variability of deep waters in the central Drake Passage are analyzed using a 183-day record of moored velocity and temperature data. Geostrophic horizontal advection accounts for about 70 percent of the observed temperature changes during this period. A downward vertical velocity of about ± 10 m/day is required to balance the difference between local time change and horizontal advection of temperature. A daily time series of vertical velocity, calculated from these differences, indicates that vertical motions are largest during two events when cold features, possibly associated with fluctuations of the Polar Front, pass through the site.

A THEORY OF THE WIND-DRIVEN CIRCULATION
I. MID-OCEAN GYRES

Peter B. Rhines and William R. Young

A theory of the wind-driven ocean circulation is presented in which the key feature is strong deformation of interior density layers and consequent production of closed geostrophic-contours by the flow itself. The constraint imposed on the sub-surface flow by the imposition of a no-flux condition where a geostrophic contour strikes a coastal boundary is thus removed. Within regions where the geostrophic contours close, the potential vorticity is uniform. This expulsion of gradients of q to the rim of the wind-driven gyre relies on a lateral eddy flux of potential vorticity or equivalently (for gyre scale mean flows) a vertical transport of momentum by eddy 'form drag'. The same result can also be obtained by invoking interfacial drag proportional to the velocity difference between layers as a specific model of form drag.

The circulation models constructed here are a simple application of the potential vorticity homogenization theory of Rhines and Young (J. Fluid Mech., 122, 347-367, 1982). There it was argued that potential vorticity homogenization amounts to a singular perturbation with respect to eddy processes; infinitesimal eddy fluxes can produce a finite mean flow in a region where the geostrophic contours close. In this article we show how the extent of the homogenized region, and the three dimensional structure of the mean flow within it, follows directly by requiring the potential vorticity to be uniform.

The theory exhibits the poleward migration of gyre centers with depth, and an abrupt poleward gyre boundary familiar to observations of the major subtropical current systems. The Sverdrup constraint on the vertically integrated velocity applies throughout. The solutions develop discontinuities, which are important to their maintenance.

Comparisons are made with classical advective thermocline theory. The major difference is that we consider the development of a gyre-like circulation on a known basic density profile, over a 'fast' time-scale, with evolution of the basic stratification left to a 'slow' time-scale. Vertical eddy momentum transport (which is also a lateral potential vorticity transport), usually ignored in the classical theory, gives results that are unique and almost independent of details of the eddy processes. The lateral eddy fluxes of potential vorticity become very weak once the circulation is spun up, yet

they are essential to its creation and existence. The solution near outcropping regions, where fluid is injected from the mixed layer, is not calculated here. Coastal boundaries are omitted from this study to simplify the development. The indications are that western boundary currents, though important to the vertically integrated dynamics, play a weak role on the 'interior' density surfaces. They are treated in a succeeding paper (Young and Rhines, J. Mar. Res., 40, 3, 849-872, 1982).

WALTER HOXTON'S 1735 DESCRIPTION OF THE GULF STREAM

Philip L. Richardson

In 1735 Walter Hoxton, on his chart of Chesapeake Bay, gave an early and accurate description of the western Gulf Stream. Hoxton's pioneering measurements by shipdrift of the mean limits, direction and speed of the Gulf Stream were the first to show that the Stream is a narrow, swift boundary current which leaves the coast near Cape Hatteras and turns eastward near $38°N$ latitude. The Hoxton description of the Stream antedates by 35 years the Franklin-Folger chart of the Stream.

EXPLORATORY OBSERVATIONS OF ABYSSAL CURRENTS IN THE SOUTH ATLANTIC NEAR VEMA CHANNEL

William J. Schmitz, Jr. and Nelson G. Hogg

Vema Channel (nominal location $30°S$, $40°W$) is a major passage for the flow of Antarctic Bottom Water on its way northward from the Argentine Basin to the Brazil Basin. New data based on approximately year-long current meter deployments at abyssal depths yield mean kinetic energies as strong as $240 \text{ cm}^2\text{s}^{-2}$, and eddy kinetic energies from 8 to $40 \text{ cm}^2\text{s}^{-2}$.

The highest value of mean kinetic energy in Vema Channel ($240 \text{ cm}^2\text{s}^{-2}$) is much larger than that ($\sim 20 \text{ cm}^2\text{s}^{-2}$) found in the flow of Antarctic Bottom Water near the Ceara Rise, and comparable to values of $220 \text{ cm}^2\text{s}^{-2}$ for the southward flow of North Atlantic Deep Water near the Blake-Bahama Outer Ridge. The largest mean kinetic energy yet observed to be associated with the Gulf Stream System in the abyssal depth range is about $100 \text{ cm}^2\text{s}^{-2}$.

Eddy kinetic energies of $8 \text{ cm}^2\text{s}^{-2}$ are comparable to estimates (at similar depths) from areas at roughly equivalent latitudes, like MODE (Mid-Ocean Dynamics Experiment, nominal location $28°N$, $70°W$). However, abyssal kinetic energies as large as $40 \text{ cm}^2\text{s}^{-2}$ are normally found only near strong current regimes, in contrast to values of roughly $1 \text{ cm}^2\text{s}^{-2}$ in the ocean interior. Values of 18 to $64 \text{ cm}^2\text{s}^{-2}$ have been observed near the southward flow of North Atlantic Deep Water on and adjacent to the Blake-Bahama Outer Ridge near $30°N$, and up to $20 \text{ cm}^2\text{s}^{-2}$ in the flow of Antarctic Bottom Water over the Ceara Rise. The strongest abyssal eddy field yet observed, ~ 100 to $150 \text{ cm}^2\text{s}^{-2}$, occurs near the Gulf Stream.

IS THE SOUTH PACIFIC HELIUM-3 PLUME DYNAMICALLY ACTIVE?

Henry M. Stommel

It is suggested that the hydrothermal vents of the South Pacific Rise produce a beta-governed circulation at mid-depth, and that perhaps the associated plume of excess ^3He (Lupton and Craig, Science, 214, 13-18, 1981) points westward because of the dynamics of this circulation rather than as a passive tracer.

DESCENT OF BOTTOM WATER ALONG
THE RISE IN THE BRAZILIAN BASIN

Henry M. Stommel, Robert J. Stanley,
George P. Knapp, Robert A. Knox and
Anthony F. Amos

Two hydrographic sections made by R/V ATLANTIS II in June 1972 are presented to confirm the existence of an abrupt drop in level of deep isotherms along the Brazil coast at about 15°S latitude. The phenomenon is explicable in terms of the Arons-Stommel (Deep-Sea Research, 19, 707-718, 1972) model of a bottom slope current as a result of supercritical slope of the bottom at the Abrolhos shoals which terminate the onshore stagnant region.

THE DEEP WATER
OF THE CENTRAL INDIAN BASIN

Bruce A. Warren

Two deep CTD (conductivity, temperature, depth sensor) sections were occupied by USNS WILKES in the Central Indian Basin during April 1979, one across the basin along Lat. 12°S, and the other from Lat. 12°S to 1°N along Longs. 88-89°E. These observations, in combination with other (mostly recent) data, demonstrate a two-layer structure in the deep water of the basin. The upper deep water (2000-3800 m) is supplied from a mid-depth western-boundary current flowing directly northward from the Antarctic along the eastern flank of the Central Indian Ridge. The water in this current is relatively high in dissolved-oxygen concentration, and low in salinity and the concentrations of dissolved silica, phosphate, and nitrate. These features, diminishing in strength away from the western boundary, may be traced across much of the basin, and are consistent with a poleward interior flow fed by the boundary current. The volume transport of the upper deep water in the western-boundary current at Lat. 12°S is estimated geostrophically as about $3 \times 10^6 m^3 s^{-1}$.

In contrast, the lower deep water (depth > 3800 m) derives from the deep western-boundary current in the West Australian Basin by overflow across the Ninetyeast Ridge, principally at Lat. 10°S, and perhaps also at Lat. 5°S. The overflow water is characterized most prominently by low temperature and high oxygen concentration. These anomalies demonstrate that, in a dynamically consistent fashion, the overflow leaves the Ninetyeast Ridge in a zonal "jet" flowing across the basin to supply a western-boundary current on the other side; during the course of its westward passage, the "jet" discharges water to the south and appears also to absorb water from the north. The volume transport of the overflow near the deep sill on the Ninetyeast Ridge at Lat. 10°S is estimated geostrophically as about $0.4 \times 10^6 m^3 s^{-1}$; there may be an additional inflow of about $0.1 \times 10^6 m^3 s^{-1}$ across the deep saddle at Lat. 5°S. Water-property comparisons suggest that this transport is enhanced perhaps threefold by entrainment during its descent of the Ninetyeast Ridge.

WHY IS NO DEEP WATER FORMED
IN THE NORTH PACIFIC ?

Bruce A. Warren

According to climatological data, the low salinity of near-surface water in the northern North Pacific, which reduces its density so much as to prevent sinking to great depth there, is due to the small regional evaporation rate (which allows a substantial net freshwater input to the surface layer from precipitation and runoff), in combination with the small rate of flow through the surface layer (which amplifies the effect of the freshwater flux on the salinity). The low evaporation rate is due in turn to the relatively low surface temperature (decreasing the specific humidity of the air at the air-sea interface), which seems to be caused mainly by the relatively large proportion of cold upwelling water in the inflow to the surface layer, contrasting with that in the northern North Atlantic where warm surface water to the south is the principal component of inflow. The reduction in southern inflow--and thereby in through-flow as well--results somewhat from the absence of a sink for surface water in any analogue to the Norwegian Sea, but probably in greater part from the more southerly extent of the subpolar gyre in the North Pacific than in the North Atlantic, whereby little water from the subtropical gyre passes through the

northern North Pacific. The latter feature indicates a linkage between deep-water formation in the northern hemisphere and the distribution of wind-stress curl. Some aspects of this process by which cooling of sea-water can reduce its density--by decreasing its salinity through diminished evaporation--are explored in a simple model.

A THEORY OF THE WIND-DRIVEN CIRCULATION II. GYRES WITH WESTERN BOUNDARY LAYERS

William R. Young and Peter B. Rhines

The quasigeostrophic, wind-driven circulation theory given by Rhines and Young (J. Mar. Res., Suppl. to 40, 559-596, 1982) is extended in two directions.

First, we consider forcing patterns which are not contrived so as to close without a western boundary layer. The resulting barotropic circulation pattern has the well known east-west asymmetry produced by the β-effect. Our goal is to present a thorough description of the associated density field and baroclinic currents as predicted by the theory of Rhines and Young.

Secondly, we consider the problem of closing the circulation by appending western boundary layers. We argue that in the southern region, where fluid enters the boundary layer from the Sverdrup interior, an inertial boundary layer forms. In the northern region, where fluid leaves the boundary layer, there is a damped, stationary, baroclinic Rossby wave which provides the dissipation required to balance the forcing. This wave is neutrally stable according to the Charney-Stern criterion for baroclinic instability, and the flow is suggestive of finite amplitude baroclinic instability in which the disturbance has equilibrated by reducing the supercriticality of the mean flow.

RINGS, EDDIES

A SIMPLE FORMULA FOR VERTICAL EDDY DIFFUSION COEFFICIENTS UNDER CONDITIONS OF NON-NEUTRAL STABILITY

Brian Henderson-Sellers

Vertical turbulent transport of head and momentum in water bodies is often parameterized as the neutral value of the appropriate (vertical) eddy diffusion coefficient, multiplied by a function of the gradient Richardson number. An analysis of previously published formulae for these stability functions shows that they are not consistent with observed values for the ratio between non-neutral and neutral values of the vertical eddy diffusion coefficients (Ueda et al., Quart. J. Roy. Meteorol. Soc., 107, 561-578, 1981) nor with observed values of the turbulent Prandtl number or the flux Richardson number (Linden, Geophys. Astrophys. Fluid Dyn., 13, 3-23, 1979). A new formulation for the stability function in the case of turbulent heat transfer is proposed which is of an inverse quadratic form. It is shown that this representation, together with an appropriate inverse linear form in the case of momentum transfer, is in excellent agreement with recent data.

INFLUENCE OF THE GULF STREAM UPON THE SHORT TERM EVOLUTION OF A WARM CORE RING

Terrence M. Joyce, Raymond W. Schmitt and Marvel C. Stalcup

A large anticyclonic, Gulf Stream ring was surveyed during September 1981, and included two expendable bathythermographic (XBT) surveys, a conductivity-temperature-depth (CTD) survey, and continuous underway measurements of velocity in the upper 100 m using an acoustic doppler velocimeter. The initial XBT survey revealed an elliptically shaped ring, over 240 km in diameter, with maximum surface velocities near 2 m s^{-1}, situated well away from the Gulf Stream. However, the later CTD and XBT surveys showed that over a 12-day period a northward meander of the Gulf Stream enveloped part of the ring. This caused a loss of water from the ring, resulting in both a decrease in ring diameter and a shoaling of the thermocline. Using the

tight relationship between geopotential anomaly (dynamic height) and isotherm depths, we estimate that approximately 33 percent of the geopotential anomaly signature of the ring was lost due to this event. Clearly, where such interactions with the Gulf Stream occur, they play an important role in the evolution of the Warm Core Rings.

EDDY KINETIC ENERGY IN THE NORTH ATLANTIC FROM SURFACE DRIFTERS

Philip L. Richardson

One hundred and ten satellite-tracked, freely-drifting buoys measured velocities and trajectories of the near-surface currents in the North Atlantic. Mean velocity values and the velocity variance about the mean were calculated for different regions. A horizontal map of eddy kinetic energy was prepared on a $2°$ by $2°$ grid between latitudes 20-55°N. Maximum eddy energy (~ 3000 cm^2 sec^{-2}) coincides with the high speed Gulf Stream jet where it begins large amplitude meanders near 37°N, 67°W. A tongue of high eddy energy coincides with the Stream's path eastward and around the Grand Banks into the Newfoundland Basin where values of 1000 cm^2 sec^{-2} are found. A weaker tongue extends eastward across the Mid-Atlantic Ridge near 45°N. A second weak extension reaches southeastward from the Stream and crosses the mid-Atlantic Ridge between 30-35°N. North and south of the Stream, eddy energy diminishes rapidly to values of 200 cm^2 sec^{-2} in the mid-gyre region and 100 cm^2 sec^{-2} in the eastern North Atlantic and North Equatorial Current.

Although the gross distribution of eddy energy is similar to that determined from ship drift measurements, there are significant differences. Eddy energy from drifters amounts to about twice the value measured by ship drift in the Gulf Stream and one half the ship drift values in the mid-gyre. It is suggested that these differences are due to the horizontal averaging of mesoscale motion and the errors in navigation, both of which are problems with the use of the ship drift technique.

A VERTICAL SECTION OF EDDY KINETIC ENERGY THROUGH THE GULF STREAM SYSTEM

Philip L. Richardson

Ocean current observations made by drifting buoys, SOFAR (sound fixing and ranging) floats and current meters are combined to produce the first section of eddy kinetic energy through the Gulf Stream and subtropical gyre along 55°W. Eddy kinetic energy has a peak of 2000 cm^2 sec^{-2} near 39°N and decreases latitudinally and vertically to a low of 0.5 cm^2 sec^{-2} in the abyssal gyre interior (4000 m, 28°N). Still farther south, there is a small increase of energy in the region of the North Equatorial Current.

MID-LATITUDE MESOSCALE VARIABILITY

William J. Schmitz, Jr., William R. Holland and James F. Price

Neither homogeneous quasi-geostrophic turbulence nor the effect of eddies on the interior ocean circulation remains the major focus of mesoscale research as was the case for much of the preceding 20 years following identification of the phenomena. Concentration on basin-wide geographical exploration of eddy properties was rather well established by 1978. Over the last few years, a promising zero-order description and rationalization of the mesoscale field has become available. That is, eddy energy is largest near strong flows (intensification not only in western boundary currents, but along their mid-latitude open-ocean extension), roughly as indicated by gyre-scale numerical models where eddies develop as a result of instability processes in the mid-latitude jet and recirculation regimes, and then propagate into the ocean interior. Our point of view is that mesoscale eddies drive recirculations but do not play a crucial role in the dynamics of the mean flow in the ocean interior (in the North Atlantic, for example, the idea is that the downstream increase in transport of the Gulf Stream is eddy-driven but not the flow through the Florida Straits). In addition, the fluctuating response to forcing by variable winds may now be widely perceived as forming the horizontally homogeneous background signal in subtropical gyres. The time-dependent field associated with thermohaline flows at abyssal depths also has a special character.

THE VELOCITY STRUCTURE OF THE UPPER OCEAN IN THE PRESENCE OF SURFACE FORCING AND MESOSCALE OCEANIC EDDIES

Robert A. Weller and David Halpern

One goal of the Joint Air-Sea INteraction Experiment (JASIN) was to investigate the structure of the near-surface velocity field and to attempt to quantify what fraction of that field was related to the local wind. Toward that end, in the late summer of 1978, two moorings were deployed in the northern Rockall Trough with oceanographic instrumentation concentrated in the upper 100 meters of the ocean. Simultaneous observations were made of the surface winds at each mooring and, adjacent to one of the moorings, of the velocity field at depths of from 79 to 1000 meters. Energetic, eddy-like circulation dominated the velocity field in the JASIN area at depths shallower than approximately 800 meters. However, both the velocity and the vertical shear of horizontal velocity showed variability that increased with proximity to the surface.

Empirical orthogonal functions, computed to separate the velocity data into uncorrelated modes of variability, showed that over 97 percent of the variability in the upper 300 meters was distributed among only three vertical modes. The first function had little depth dependence; the second had strong depth-independent flow in the depth range of the mixed layer and weak flow in the opposite direction at all depths below; and the third had strong flow near the surface, strong flow in the opposite direction just below the base of the mixed layer, and weaker flow at all other depths. Function one alone provided a near-complete description of the velocity variability below 85 m, where the flows associated with the eddy-like circulation and the barotropic semi-diurnal tide were the dominant components. At 85 m and above all three functions were necessary to provide a complete description. Temporal variability of function two was coherent with the local wind stress at the inertial frequency, but, at lower frequencies, resulted in transport in the mixed layer to the southeast that was not coherent with

the local wind. Low frequency temporal variability of function three was coherent with the local wind stress; at these frequencies the velocity vector of function three nearest the surface was directed to the right of the wind stress vector and the velocity vector just below the base of the mixed layer was directed to the left of the wind stress. Thus, forcing by the local wind can account for some but not all of the increased variability found near the surface.

S U R F A C E   L A Y E R
P R O C E S S E S
A N D   M E T E O R O L O G Y

A NOTE ON THE HEAT BALANCE OF THE MEDITERRANEAN AND RED SEAS

Andrew F. Bunker, Henry Charnock and Roger A. Goldsmith

The Mediterranean and Red Seas are used as test volumes in an attempt to assess the accuracy of estimates of climatological air-sea fluxes calculated using meteorological observations from merchant ships.

Although the radiative flux estimates are subject to error, especially those of net longwave radiation, it is difficult to obtain an acceptable heat balance if the evaporative heat fluxes are calculated using the values for the exchange coefficient now widely accepted by specialists in near-surface turbulent transport. Larger coefficients seem to be needed: they may be a compensation for ships' avoidance of high winds and for systematic errors of observation.

NEARSURFACE MEASUREMENTS OF
QUASI-LAGRANGIAN VELOCITIES IN OPEN WATER

James H. Churchill and Gabriel T. Csanady

Nearsurface water velocities have been measured in the coastal zone of Lake Huron and Cape Cod Bay by tracking drifters and drogues using acoustic travel time and compass sighting techniques. The nearsurface current, defined as the velocity of nearsurface drifters and drogues relative to a drogue set at 1.8 m, varied on the depth scale on the order of 1 m, and was directed nearly parallel to the wind and to predominant wave propagation velocity. There was no clear relationship between wind speed and nearsurface current velocity. There was, however, a definite increase of relative velocity magnitude with sea state, suggesting that sea state is a better direct indicator of wind stress than wind speed. Velocity profiles were logarithmic with depth to order 1 m depth. Realistic values of stress were calculated using a law of the wall formula and a Kármán's constant of 0.4. Anomalously high values of wind stress were inferred from velocity profiles observed during conditions of light wind and steady swell. These may be due to the similarity of Stokes drift distribution to turbulent shear flow profiles.

THE FREE SURFACE TURBULENT SHEAR LAYER

Gabriel T. Csanady

"Horsehair" drifters, 0.2 m square, filter out small scale disturbances of a wind-blown free surface and yield a mean drift profile. Field observations, using this technique, were carried out off Long Island, in Cape Cod Bay and in Lake Huron. The results may be interpreted in the framework of a turbulent "wall layer" analogy, with the following results:

(1) The logarithmic law is valid below a quasi-viscous sublayer, with the same Karman's constant as above a solid surface;

(2) The effective viscosity v_e at the free surface, due to the small scale disturbances, is typically two orders of magnitude greater than the molecular viscosity;

(3) The roughness length on the water side of the interface is proportional to $v_e/u*$, and is typically two orders of magnitude greater than on the air side.

INTERNAL WAVE WAKE OF A MOVING STORM.
PART I: SCALES, ENERGY BUDGET
AND OBSERVATIONS

James F. Price

The ocean's baroclinic response to a steadily moving storm is analyzed using an inviscid, multi-layered, numerical model. A principal goal is to describe how thermocline-depth motions are generated by wind-forcing. This first part of a two-part study provides an account of the response to a tropical hurricane. Parameter dependence is examined in the second part.

The baroclinic response to a moving hurricane is dominated by a spreading, three-dimensional wake of inertial-internal waves. These waves initially have large horizontal spatial scales set directly by the storm. Their along-storm track wavelength is the storm translation speed times the wave period, which is typically five percent less than the local inertial period. Their cross-track scale is the storm scale. If the storm is intense, e.g., a hurricane, finite amplitude effects generate a double inertial frequency wave and considerably smaller spatial scales.

An important qualitative result is that the vertical scale is large compared to the thermocline thickness. The initial isopycnal displacement is almost uniform through the thermocline, and the associated pressure gradient couples the mixed-layer to the entire thermocline. Vertical energy propagation is very rapid near the storm track, $O(100 \text{ m day}^{-1})$, and is largely responsible for a rapid decay of mixed-layer velocity (e-folding in $\simeq$ 5 wave periods). Model-computed frequencies, vertical wavelength, and mixed-layer velocity decay rate are roughly consistent with velocity observations made in the wake of Hurricane Eloise in 1975.

INTERNAL WAVE WAKE OF A MOVING STORM. PART II: PARAMETER DEPENDENCE

James F. Price

The internal wave wake problem treated by Price in Part I is studied by numerical experiment and by analysis of a simple one-dimensional model. The goal is to explore parameter dependence and to obtain a better physical description of downward energy propagation.

The horizontal structure of the thermocline velocity depends upon the nondimensional storm speed $S = U_H/2Rf$, where U_H is the (dimensional) storm translation speed, R is the storm scale and f is the Coriolis parameter. In the wake of a "slow" storm, $S < 1$, the thermocline velocity field has a single maximum near the storm track; for a "fast" storm, $S \gtrsim 2$, there are two maxima well away from the track which have opposite phase. Parameter S also sets the amplitude ratio of the geostrophic and wave components of the wake.

Within the mixed-layer, the super-inertial (or blue) frequency shift ν of the wave frequency is proportional to the mixed-layer Burger number $M \sim g'h_1/4R^2f^2$, where h_1 is mixed-layer thickness and g' is the thermocline buoyancy. Within the thermocline, ν is proportional to $J(z)T$, where $T = Mb/h_1$ is the thermocline Burger number, b is the thermocline scale thickness, and J is an $O(1)$ function which increases with depth. T is thus a measure of the thermocline thickness. When T is $\lesssim 1$, which obtains for all but very small storm systems, the ocean thermocline is thin in the sense that the initial isopycnal displacement penetrates the full thermocline with very little change of phase or amplitude. In this parameter regime, the wake is better described as a forced response, than as a vertically propagating wave.

The wake of a zonally translating storm is significantly modified by the β-effect within about five inertial periods. Because the f-plane solution for velocity is itself asymmetric, the β-plane solution depends upon the sense of the storm's zonal translation.

WIND MEASUREMENTS FROM AN ARRAY OF OCEANOGRAPHIC MOORINGS DURING JASIN 1978

Robert A. Weller, Richard E. Payne, William G. Large and Walter Zenk

During the Joint Air-Sea Interaction (JASIN) experiment conducted in the northern Rockall Trough in the late summer of 1978, oceanographic moorings with surface buoys carrying wind recorders were deployed in an array designed to investigate the variability of the near-surface wind field at scales of up to 200 km and to provide, together with observations taken on board the research vessels participating in JASIN, ground truth measurements for SEASAT. During most of the experiment the wind field was characterized by spatial scales large compared to the separations between the buoys. On several occasions spatial differences associated with cold fronts were identified and it was possible to track the passage of the front through the array. However, quantitative analysis of the variability of the wind field was complicated both by a lack of data due to mechanical failures of some instruments and by significant differences in the performance of the diverse types of wind recorders. Re-evaluation of the instruments used in JASIN and recent comparison of some of these instruments with more conventional sets of wind sensors confirm the possibility that there is significant error in the JASIN wind measurements made from the buoys. The Vector Averaging Wind Recorder on W2, one of the few instruments to recover a full length record, was chosen during the SEASAT-JASIN workshop as the JASIN standard, and in preparing the ground-truth for SEASAT all other wind data was corrected to agree with that instrument. Unfortunately this re-evaluation found that the Vector Averaging Wind Recorder had performance characteristics that were among the most difficult to explain and that it probably introduced the most error into the measurement of the mean near-surface wind.

SEASAT: the satellite launched by NASA for remote sensing of oceanic phenomena.

THEORETICAL MODELS

EFFECTS OF VARIABLE AND ANISOTROPIC DIFFUSIVITIES IN A STEADY-STATE DIFFUSION MODEL

Laurence D. Armi and Dale B. Haidvogel

The hypothesis that variations in eddy diffusivity may account for some aspects of the observed distributions of oceanic scalars is examined by generating solutions to the diffusion equation with spatially variable and/or anisotropic eddy diffusivity. In particular, the solutions generated here demonstrate how a purely diffusive field, with variable and anisotropic diffusion, can itself generate tongue-like property distributions. Although tongues of various oceanic properties have often been interpreted as due primarily to advective effects, such interpretations must be viewed with caution when the gradients of eddy diffusivity are comparable to, or greater than, the local velocity field.

LOW RESOLUTION NUMERICAL SIMULATION OF DECAYING TWO-DIMENSIONAL TURBULENCE

Andrew F. Bennett and Dale B. Haidvogel

Numerical simulations of two-dimensional turbulence show that $O(K^{-1})$ and $O(K^{-4})$ energy spectra--described by Fox and Orszag (Phys. Fluids, 16, 169-171, 1973) as enstrophy-equipartitioning and strongly dissipating turbulence, respectively, occur independently of the type of dissipation mechanism, and the inclusion of forcing and the β-effect. In both states the modal decorrelation rate η depends strongly upon wavenumber in accordance with the equations of a direct interaction approximation (Kraichnan, Phys. Rev., 109, 1407-1422, 1958), but in conflict with the hypothetical wavenumber independence of η in an enstrophy-cascading inertial similarity range. Implications of geophysical fluid dynamical modeling are discussed.

THE THERMOHALINE DRIVING MECHANISM OF OCEANIC JET STREAMS

Gabriel T. Csanady

Worthington (In: Studies in Physical Oceanography, a tribute to George Wüst on his 80th birthday, Vol. 1, A. L. Gordon, ed., 169-178, 1972) advanced the hypothesis that winter cooling of the Gulf Stream south of New England is the cause of the Stream's winter intensification. That loss of buoyancy should result in increased velocity and transport in an oceanic jet stream seems at first paradoxical. However, if a pattern of thermohaline circulation should arise in the upper layers of the Stream, it could play a role similar to that of the Hadley circulation in the atmosphere, which drives the subtropical jet stream. This possibility is examined here with the aid of a two-layer model, with the light layer being only "nearly homogeneous."

Thermohaline circulation arises in the light layer because the heat loss per unit mass near the front is much greater than farther away, partly because of greater surface heat transfer to the unmodified air mass, partly on account of lesser penetration of surface cooling above a shallow pycnocline. The circulation carries heat toward the front, as well as streamwise momentum. The long-term cumulative effect (over an entire winter) of the momentum transport is to create substantial convergence just south of the front, causing a deepening of the thermocline and leading to increased transport. Order of magnitude estimates suggest, however, that the thermocline circulation in isolation is not strong enough to produce the observed effects. It appears that the strong anticyclonic curl of the wind stress-force over the light layer just south of the front is at least a contributory factor in Gulf Stream intensification.

WAVES AND CIRCULATION DRIVEN BY OSCILLATORY WINDS IN AN IDEALIZED OCEAN BASIN

Dale B. Haidvogel and Peter B. Rhines

We examine, via direct numerical integration, the transient and rectified response of a flat-bottomed barotropic ocean to a spatially localized oscillatory

wind-stress pattern. These experiments exemplify in many respects the dynamics which drive the deep motion in recent eddy-resolving ocean circulation studies (e.g., Holland and Rhines, J. Phys. Oceanogr., 10, 1010-1031, 1980), and may be contrasted with the results of Pedlosky (J. Atmos. Sci., 22, 267-272, 1965) and Veronis (Tellus, 18, 67-76, 1966) for spatially broad, time-dependent forcing.

By considering doubly re-entrant (periodic) and closed basin geometries, the structure and magnitude of the induced circulation is shown to depend most critically on the form of the mean quasi-geostrophic contours (which are closed and blocked, respectively, in the periodic and basin geometries). In both situations, however, the forced primary wave field may be usefully understood by appeal to the radiation pattern of a time-periodic Green's function, and (in a basin) its image in the western boundary.

The dynamics of the time-mean rectified circulation are seen to relate most directly to the mean eddy potential vorticity flux $\overline{v'q'}$ (and not to the Reynolds stress $\overline{u'v'}$). In particular: Eulerian vorticity budgets indicate the dominance of the turbulent Sverdrup balance $[\beta v \simeq - \overline{(v'q')}]$ in nearly all parts of the flow; Lagrangian (particle-wise) balances clearly emphasize the regions of counter-gradient q fluxes in providing the propulsion necessary for fluid particles to cross the mean quasi-geostrophic contours. Although these flows do not strictly comply with the assumptions of recent q-transport theories, nonetheless all the qualitative (and some of the quantitative) features predicted by these theories are confirmed in the simulations.

THE VENTILATED THERMOCLINE

James R. Luyten, Joseph Pedlosky and Henry M. Stommel

A simple theoretical model for the oceanic thermocline and the associated field of currents is presented. The model consists of a finite but arbitrarily large number of inviscid, homogeneous fluid layers each with a different density. The dynamical balances are everywhere Sverdrupian. In regions where the Ekman pumping is negative (downward) the surface density is specified, i.e., the position of the outcrop of density interfaces is specified. This outcropping of density layers allows deep motion to be excited by the ventilation provided by Ekman pumping, even in latitudes far south of the outcrop where the layer is shielded from direct influence of the wind. Analytical solutions are presented in the case where the density outcrop lines are coincident with latitude circles. The solutions are not self-similar and important sub-domains of the solution are defined by critical potential vorticity trajectories which separate the ventilated from the unventilated regions in the lower thermocline. These critical trajectories also separate regions of strong variations in potential vorticity from regions of fairly weak variation in potential vorticity although the small variations in potential vorticity in the latter are crucial to the dynamics.

Comparison is made between the predictions of the model and data from the Atlantic with encouraging results.

A SIMPLE MODEL FOR NONLINEAR CRITICAL LAYERS IN AN UNSTABLE BAROCLINIC WAVE

Joseph Pedlosky

Weakly nonlinear theory is developed for finite amplitude dynamics of a slightly dissipative baroclinic wave at the point of minimum critical shear in the β-plane two-layer model. At this parameter setting the nonlinear theory provides a simple manifestation of critical layer dynamics since the Doppler-shifted frequency vanishes in one of the two layers. Calculations show that when the dissipation is proportional to the potential vorticity and is weak, the new equilibrium steady state has uniform potential vorticity in the critical layer although this is not required for wave stabilization. The spatial harmonics of the fundamental play an important role in both the transient and final state. For a weakly dissipative flow, the potential vorticity due to the harmonics is conserved along streamlines of the fundamental wave. An analytical theory is given for the equilibrated wave amplitude based on the assumption of uniform potential vorticity in the critical layer, and this prediction agrees well with the calculations.

Potential vorticity smoothing does not occur when either dissipation or time dependence becomes large.

LECTURES IN GEOPHYSICAL FLUID DYNAMICS

Peter B. Rhines

In a series of five lectures, basic theories of large-scale waves and circulation in planetary fluids are given. Included is a discussion of transport and cascade of passive scalars in steady or chaotic circulations.

T U R B U L E N C E   A N D   M I X I N G,

F I N E   S C A L E   P R O C E S S E S

FINE AND MICROSTRUCTURE OBSERVATIONS ON A HYDROGRAPHIC SECTION FROM THE AZORES TO THE FLEMISH CAP

Daniel T. Georgi and Raymond W. Schmitt

Continuous conductivity-temperature-depth-dissolved oxygen (CTD) data are used to investigate the spatial distribution of fine and microstructure between the Azores and the Flemish Cap. The CTD data are used to calculate a conductivity microstructure Cox number. This indicator summarizes microstructure variance from the .08 to 2 m vertical wavelength range. The CTD data are also used to calculate the finestructure temperature Cox number. Finally, the fine and microstructure data are combined to calculate lateral flux and flux divergence for the waters east of the North Atlantic Current.

The distribution of the conductivity Cox number indicates that vertical mixing is more intense above the base of the main thermocline ($5°C$ isotherm) than below it and that mixing is more prominent near the North Atlantic Current than farther east. Stations near the front indicate elevated conductivity Cox numbers associated with intrusive features. The hydrographic sections and the finestructure data reveal the presence of intrusive features along the entire section, particularly at the depth of the mid-thermocline oxygen minimum. The finestructure variance exceeds the variance expected from internal wave straining by a factor of 2 to 8.

Lateral fluxes and eddy diffusivities are calculated from the finestructure data with the model proposed by Joyce (J. Phys. Oceanogr., 7, 626-629, 1977). The calculated lateral fluxes and eddy diffusivities, $O(10^3 m^2/s)$, indicate that considerable mixing is occurring at the depth of the oxygen minimum. As the microstructure data indicate that vertical mixing weakens to the east and the finestructure intensities decrease to the east, we conclude that there is a net flux divergence at the level of the oxygen minimum. This flux divergence is consistent with the water-mass modifications required to convert Gulf Stream waters into the waters found in and to the east of the North Atlantic Current.

HOW RAPID IS PRANDTL-BATCHELOR EXPULSION?

Peter B. Rhines and William R. Young

The homogenization of a passive 'tracer' in a flow with closed mean streamlines occurs in two stages: first, a rapid phase dominated by shear-augmented diffusion over a time $\sim P^{1/3}(L/U)$, where the Peclet number, $P = LU/K$, (L, U, K are length scale, velocity scale and diffusivity) in which initial values of the tracer are replaced by their (generalized) average about a streamline; second, a slow phase requiring the full diffusion time $\sim L^2/K$. The diffusion problem for the second phase, where tracer isopleths are held to streamlines by shear diffusion, involves a generalized diffusivity which is proportional to K, but exceeds it if the streamlines are not circular. Expressions are also given for flow fields that are oscillatory rather than steady.

SHEAR FLOW DISPERSION, INTERNAL WAVES AND HORIZONTAL MIXING IN THE OCEAN

William R. Young, Peter B. Rhines and Christopher J. R. Garrett

Two models of advection-diffusion in the oscillatory, sheared-velocity field of an internal wave are discussed. Our goal is to develop intuition about the role of such currents in horizontal ocean mixing through the mechanism of shear dispersion. The analysis suggests simple parameterizations of this process, i.e., those in Eqs. (7), (36) and (42). The enhanced horizontal diffusion due to the interaction of the vertical diffusion and vertical shear of the wave field can be described by an "effective horizontal diffusivity" which is equal to the actual horizontal diffusivity plus a term equal to the mean square vertical shear of horizontal displacement times the vertical diffusivity, provided the vertical length scale of the horizontal velocity field is not too small. In the limit of small vertical length scale the expression reduces to Taylor's (Proc. Roy. Soc. London, A209, 186-203, 1953) result in which the effective horizontal diffusivity is inversely proportional to the actual vertical diffusivity.

The solutions also incidentally illuminate a variety of other advection-diffusion problems, such as unsteady shear dispersion in a pipe and enhanced diffusion through wavenumber cascade induced by steady shearing and straining velocity fields.

These solutions also serve as models of horizontal stirring by mesoscale eddies. Simple estimates of mesoscale shears and strains, together with estimates of the horizontal diffusivity due to shear dispersion by the internal wave field, suggest that horizontal mesoscale stirring begins to dominate internal wave-shear dispersion at horizontal scales larger than 100 m.

TECHNICAL REPORTS

A PRELIMINARY DESCRIPTION OF THE CODE-1 FIELD PROGRAM

John S. Allen, Robert C. Beardsley, Wendell S. Brown, David A. Cacchione, Russ E. Davis, David E. Drake, Carl A. Friehe, William D. Grant, Adriana Huyer, James D. Irish, Mona M. Janopaul, Albert J. Williams and Clinton D. Winant

A Coastal Ocean Dynamics Experiment (CODE) has been undertaken to identify and study the important dynamical processes which govern the wind-driven motion of coastal water over the continental shelf. The initial effort in this four-year research program is to obtain high-quality data sets of all the relevant physical variables needed to construct accurate kinematic and dynamic descriptions of the response of shelf water to strong wind forcing in the 2 to 10-day band. A series of two small-scale, densely-instrumented field experiments of four-month duration (CODE-1 and CODE-2) is designed to explore and to determine the kinematics and momentum and heat balances of the local wind-driven flow over a region of the northern California shelf which is characterized by both relatively simple bottom topography and large wind stress events in both winter and summer. A more lightly-instrumented, long-term, large-scale component has been designed to help separate the local wind-driven response in the region of the small-scale experiments from motions generated either offshore by the California Current system or in some distant region along the coast, and also to help determine the seasonal cycles of the atmospheric forcing, water structure, and coastal currents over the northern California shelf.

This report presents an overview of the CODE program and a preliminary description of the observational programs conducted during CODE-1. The various logical components of CODE are identified and described, and their relationship to the entire effort is discussed. The report itself represents a minor revision of the original cover proposal submitted to NSF in late 1979 by the principal investigators and is not a comprehensive guide nor does it contain any descriptions of the initial results from CODE-1. Scientific and engineering results will be presented elsewhere in individual technical and scientific reports. CODE has been jointly conceived by the following principal investigators (who collectively make up the CODE group): J. Allen, R. Beardsley,

W. Brown, D. Cacchione, R. Davis, D. Drake,
C. Friehe, W. Grant, A. Huyer, J. Irish,
M. Janopaul, A. Williams and C. Winant.

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TECHNICAL ACTIVITIES ASSOCIATED WITH
AN EXPLORATORY ARRAY
IN THE WESTERN NORTH PACIFIC

Keith F. Bradley

Operations activities of the Woods Hole
Oceanographic Institution's Buoy Group for
an exploratory array of deep-ocean moorings
in the western North Pacific Ocean are
described along with specific engineering
notes associated with high-current deep
moorings. The array, along $152°E$ from $28°N$
to $41°N$, was in place for about two years.
After one year the array was successfully
recovered and redeployed. Brief summaries
of each of three research cruises are
provided. An Appendix lists details of the
twenty moorings including positions, dates
deployed and recovered, instrument types
and depths and moored station numbers which
are required for specific data retrieval by
investigators. The initial scientific
publication has been prepared by Schmitz,
Niiler, Bernstein and Holland (J. Geophys.
Res., 87, C12, 9425-9440, 1982).

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FRICTIONAL SECONDARY CIRCULATION NEAR
AN UPWELLED THERMOCLINE

Gabriel T. Csanady

A first order, linear analysis of
thermocline upwelling shows that a
quasigeostrophic baroclinic jet accompanies
the upwelling. The secondary circulation
induced in such a flow field in a
meridional plane by turbulent friction is
investigated. A double Ekman layer is
found to form at the thermocline, of a few
meters in thickness. The suction of this
Ekman layer destroys the primary flow by
the "spin-up" mechanism in a period of
which the order of magnitude is tentatively
estimated at 100 hours. Thus the primary
flow must be reestablished by successive,
reasonably frequent wind-stress impulses to
maintain a quasi-stationary upwelling.

The lower side Ekman layer on the
thermocline is fed from a free shear layer
(turbulent "Stewartson layer") underneath
the free surface-thermocline intersection,
which thus becomes an upwelling zone. The
width of the turbulent Stewartson layer is
estimated to be the velocity difference
divided by the Coriolis paramter, i.e.
typically of the order of 1 km.

Note: The material of this report was
presented ten years ago at a symposium, but
on account of its speculative nature,
remained unpublished. Several colleagues
were, however, kind enough to quote it on
occasion and some have requested copies.
In order to make it more readily available,
it has now been re-issued as a WHOI report.

Prepared for: NOAA, Great Lakes
Environmental Research Laboratory,
Ann Arbor, Michigan.

WHOI Technical Report 82-52.

DESCRIPTION AND EVALUATION
OF THE ACOUSTIC PROFILING OF OCEAN
CURRENTS (APOC) SYSTEM USED ON
R/V OCEANUS CRUISE 96
ON 11-22 MAY 1981

Terrence M. Joyce, Stephen R. Rintoul, Jr.
and R. Lorraine Barbour

The underway current profiling system
used in this study consists of a
microprocessor-controlled data logger that
collects and formats data from a four-beam
Ametek-Straza 300 kHz acoustic Doppler
current profiler, heading from the ship's
gyrocompass, and navigation information
from a LORAN-C receiver and a satellite
navigation unit. Data are recorded on
magnetic tape and some real time
calculations are made. The system was
first used on a May 1981 cruise aboard the
R/V OCEANUS in the western North Atlantic.
Horizontal currents were profiled to depths
of 100 m. Time averaging is required to
remove effects of ship motion. Errors in
our ability to profile ocean currents are
estimated to be 5-10 cm s^{-1} for a
ten-minute vector average. An
intercomparison is made with a moored
vector measuring current meter (VMCM). The
mean difference in hourly-averaged APOC and
VMCM currents over the four-hour inter-
comparison is a few mm s^{-1}. Data from a
variety of oceanic regimes are presented
and discussed: these regimes include two
Gulf Stream crossings, a warm core ring
survey, and shallow water in a frontal zone
to the east of Nantucket Shoals.

Prepared for: NASA under Grant
NAG 1-91.

WHOI Technical Report 82-48.

A COMPILATION OF MOORED CURRENT METER DATA, WHITE HORSE PROFILES AND ASSOCIATED OCEANOGRAPHIC OBSERVATIONS, VOLUME XXIX (INDEX, 1979)

Ellen Levy, Ann Spencer, Gerald J. Needell, Gretchen Hund and James R. Luyten

Current and temperature measurements are presented from instruments deployed during March and April of 1979 in the western Indian Ocean, between 46°E and 62°E and between 4°S and 4°N. The experiment was part of the INDEX (Indian Ocean Experiment) program.

Twelve mooring sites were occupied. A total of thirty current meters were on WHOI moorings at ten of the sites. An experimental inverted echo sounder was on another WHOI mooring, and a French mooring was at the twelfth site. Most of the resulting data records are of fourteen months duration. A current profiler, the White Horse, was also used, and forty-one profiles were taken over a thirteen-week period.

Basic data from the current meters are presented in statistical tables and graphically as scatter plots, progressive vector plots, spectral plots and time series plots. Filtered time series are shown in composite displays. Time series plots are shown for the inverted echo sounder.

Basic White Horse data are presented as east and north velocity component profiles, potential temperature and salinity profiles, and potential temperature versus salinity diagrams.

Prepared for: ONR under Contract N00014-76-C-0197, NR 083-400; NSF under Grant ATM78-21491.

WHOI Technical Report 82-16.

A COMPILATION OF MOORED INSTRUMENT DATA AND ASSOCIATED OCEANOGRAPHIC OBSERVATIONS, VOLUME XXX (GULF STREAM EXTENSION AND NORWEGIAN SEA OVERFLOW INSTRUSION EXPERIMENTS), 1979-1980

Ellen Levy, Susan A. Tarbell and Nick P. Fofonoff

Current and temperature measurements are presented from instruments deployed during October and November of 1979, southeast of the Grand Banks in the North Atlantic, between 37°N and 41°N and between 42°W and 47°W.

The measurements were made as part of two concurrent experiments, the Gulf Stream Extension (GSE) and the Norwegian Sea Overflow Intrusion (NSOI) arrays. Data from the current meters are presented in statistical tables and graphically as scatter plots, histograms, progressive vector plots, spectral plots and time series plots. Filtered time series are shown in composite displays. Data from XBT, CTD and T/Ps are also presented graphically.

CTD: conductivity-temperature-depth sensor
T/P: temperature/pressure sensor
XBT: expendable bathythermograph

Prepared for: ONR under Contract N00014-76-C-0197, NR 083-400.

WHOI Technical Report 82-43.

HYDROGRAPHIC STATION DATA OBTAINED IN THE EAST CHINA SEA, JUNE 1980

Richard Limeburner and Robert C. Beardsley

Three surveys were made during June 1980 on the R/V OCEANOGRAPHER to measure the regional hydrographic structure in the East China Sea near the mouth of the Chang Jiang (Yangtze) River. The objective of the hydrographic program was to document the spatial and temporal structure of the Chang Jiang plume over the continental shelf and characterize the river's influence on the shelf water masses. A summary of the hydrographic observations made during Cruise RP-05-OC-80 on the R/V OCEANOGRAPHER is presented in graphic form.

Prepared for: NOAA under Cooperative Agreement NA81AA-H-00008; NSF under Grant OCE80-14941.

WHOI Technical Report 82-10.

HYDROGRAPHIC STATION DATA OBTAINED IN THE EAST CHINA SEA, AUGUST 1981

Richard Limeburner and Robert C. Beardsley

A hydrographic survey was made during August 1-16, 1981 on the People's Republic of China R/V SHIJIAN to measure the regional hydrographic structure in the East China Sea near the mouth of the Chang Jiang (Yangtze) River. The objectives of the hydrographic program were to document the spatial structure of the Chang Jiang discharge over the continental shelf and characterize the river's influence on the shelf water masses during a period of maximum river discharge. A summary of the hydrographic observations made during Cruise ECS81-1 on the R/V SHIJIAN is presented in graphic form.

HYDROGRAPHIC STATION DATA OBTAINED IN THE EAST CHINA SEA, NOVEMBER 1981

Richard Limeburner and Robert C. Beardsley

A hydrographic survey was made on November 18-23, 1981 on the People's Republic of China R/V SHIJIAN to measure the regional hydrographic structure in the East China Sea near the mouth of the Chang Jiang (Yangtze) River. The objectives of the hydrographic program were to document the spatial structure of the Chang Jiang discharge over the continental shelf and characterize the river's influence on the shelf water masses during a period of low river discharge. A summary of the hydrographic observations made during Cruise ECS81-2 on the R/V SHIJIAN is presented in graphic form.

WHOI PROCESSED CTD DATA ORGANIZATION

Robert C. Millard and Nancy R. Galbraith

A data storage format has been developed to be used for processed CTD data on the Woods Hole Oceanographic Institution's Digital Equipment Corporation VAX 11/780 computer. CTDVAX as defined in this report is designed as a flexible internal data format. Station data is organized by ship-cruise-project using a VAX-supplied subdirectory system on disk.

This report describes the data organization, file structures, and record formats. File naming conventions, data protection and documentation schemes are explained. Outlines are given of the data processing system in use and of the CTD data accessing utilities available on the VAX.

CTD: Conductivity-temperature-depth sensor.

OBSERVATIONS OF VERTICALLY PROPAGATING EQUATORIALLY-TRAPPED WAVES IN THE DEEP WESTERN INDIAN OCEAN

Kathleen O'Neill

An hypothesis of equatorially-trapped waves is found to be consistent with time series of vertical profiles of horizontal velocity and CTD data from the western Indian Ocean. The profiles were collected using an acoustic dropsonde, the White Horse, along the 53°E meridian. The temporal coverage is a month-long period spanning the onset of the southwest monsoon in 1976; the latitudinal coverage is 3/4°S to 5°N.

To examine the composition of the velocity field, a WKB stretching procedure was applied to the depth and a WKB normalizing procedure to the velocity. An average buoyancy frequency profile was used to reduce each velocity profile to the form which would have been observed in a uniformly stratified ocean. Removal of the variations of amplitude and scale resulting from the background density stratification makes it possible to discuss vertical wavenumbers throughout the temporal and spatial array, rather than merely local vertical wavenumbers.

Autospectral estimates reveal equatorial intensification that varies with vertical wavenumber. The hypothesis is that equatorially-trapped waves of one kind or another are the basis for the observed motion. To examine vertical propagation, dropped lagged coherences have been computed. Pairs of drops separated by the same temporal lag were grouped together to estimate cross-spectra. The results indicate the presence of a mixed Rossby-gravity wave of 60-77 day period with phase propagation downward at a vertical wavelength of 1200 in the stretched coordinate, which is equivalent to approximately three wavelengths between the thermocline and the bottom. Vertical propagation is indicated in other wavenumber bands as well, also corresponding to autospectral peaks.

If linear equatorial wave theory is applicable, zonal wavelengths can be determined from the dispersion relation, and possible forcing mechanisms can then be examined. Linear theory gives a zonal wavelength of 300-400 km for the 1200 stretched meter (sm) oscillation. The rms velocity is the same order as the phase speed, however, so that nonlinearities may not be completely negligible. Indications are of multiple processes within the same wavenumber band, a longer-period Kelvin or Rossby wave coexisting with the above-mentioned mixed Rossby-gravity wave.

CTD: Conductivity-temperature-depth sensor.
WKB: Wentzel-Kramers-Brillouin.

WARM CORE RING CRUISE # 1
R/V ENDEAVOR CRUISE NO. 74

Marvel C. Stalcup, Terrence M. Joyce,
Raymond W. Schmitt and Jane A. Dunworth

A one year multi-ship, multi-
disciplinary study of Warm Core Rings in
the North Atlantic began with a preliminary
cruise in September 1982. During this
"dress rehearsal" scientists aboard the
four research vessels KNORR, OCEANUS,
ENDEAVOR and ALBATROSS IV collaborated in
testing a variety of new equipment,
techniques and procedures while studying a
Warm Core Ring centered near 40°N, 64°W.
This report describes the observations made
aboard the R/V ENDEAVOR during this study.

LONG TERM UPPER OCEAN STUDY (LOTUS):
A SUMMARY OF THE HISTORICAL DATA
AND ENGINEERING TEST DATA

Richard P. Trask, Melbourne G. Briscoe
       and Nancy J. Pennington

Plans for the Long Term Upper Ocean
Study evolved over several years. As the
plans became more definite, a two-year
period was devoted to engineering tests at
the LOTUS site (34°N, 70°W). Many aspects
of the proposed plans were implemented
during this period in order to evaluate the
performance of the equipment and
instrumentation. This report presents a
summary of the planning and testing periods
up to but not including the first science
deployments in May 1982. Historical data
collected at the LOTUS site prior to the
engineering tests and the data collected as
part of the engineering tests are presented.

MARINE POLICY

AND OCEAN MANAGEMENT PROGRAM

David A. Ross, Director

MARINE POLICY and OCEAN MANAGEMENT

THE INTRODUCTION OF LIMITED ENTRY INTO THE NEW ZEALAND ROCK LOBSTER FISHERY

John Annala

A controlled or limited entry fishery for New Zealand rock lobsters was introduced during 1980-81. The process of introducing a limited entry fishery began in December 1977 when a moratorium on the issuance of new rock lobster fishing permits was declared. Consultations were held with industry and the public during the next two years to gauge their opinion on the introduction of a limited entry fishery. As a result of these consultations, a limited entry fishery was declared, and a policy statement governing its initial introduction was issued by the Minister of Fisheries in January 1980. The fishery was divided into ten separate controlled fishery areas, each with its own policy statement which takes into account local conditions. Upper limits to the number of licenses for each area have been set in order to prevent increases in the number of vessels fishing for rock lobsters. Discussions concerning the long-term management of the fishery are now proceeding with industry and the public.

WORKSHOP ON COOPERATIVE INTERNATIONAL MARINE AFFAIRS

James Broadus, Robert W. Knecht, David A. Ross, Kurt Shusterich and Maynard Silva

This report details the results of a workshop held at WHOI on April 20-21, 1982, as part of an effort by MPOM to assist interested developing coastal nations in formulating strategies for ocean resource use and management within their new 200-mile exclusive economic zones. Aims of the workshop were: (a) to review the nature of marine policy needs for developing countries; (b) to discuss the kinds of programs necessary to meet those needs; (c) to review the kind of program WHOI could best undertake; and (d) to review, refine and extend the program development plan for the cooperative assistance effort.

OCEAN DUMPING

John W. Farrington, Judith M. Capuzzo, Thomas M. Leschine and Michael A. Champ

This article recounts the history of attempts to restrict ocean dumping in the 1960s and early 1970s, and outlines essential considerations which must be made in reformulating a U.S. ocean dumping policy for the 1980s. The status of a wide range of present ocean dumping activities is reviewed, as are scientific and policy issues which led to the congressional ban on the ocean dumping of sewage sludge and some industrial wastes in the late 1970s. The pros and cons of near-shore vs. deep-ocean disposal are discussed. Flexibility and caution are urged in developing new ocean dumping policies, in light of the great uncertainty which remains in our knowledge of the effects of waste disposal on the marine environment.

INTERNATIONAL LAW AND SCIENTIFIC CONSULTATION ON RADIOACTIVE WASTE DISPOSAL IN THE OCEAN

Daniel P. Finn

Radioactive wastes are currently released into the marine environment from discharges into rivers and coastal waters and dumping of packaged low level waste into the deep ocean. Sea dumping will probably increase, the oceans have become subject to radioactive releases from commercial-scale reprocessing plants, and deep ocean or other marine high level waste repositories may be established.

Different marine radioactive waste disposal methodologies are subject to distinct substantive legal principles based on their location and characteristics. Current activities, primarily sea dumping, are controlled at the international level through technically-oriented consultations in international organizations which are of such long standing that such cooperation can be considered customary for marine disposal. Increased and novel marine waste disposal methodologies will require enhanced international organization, in view of both their technical characteristics and changes in the international legal and political climate.

In press: Wastes in the Ocean, Vol. 3:
Radioactive Wastes and the Ocean.
P.K. Park, I.W. Duedall, and B.H.
Ketchum, eds. New York: Wiley-
Interscience.

NUCLEAR WASTE MANAGEMENT ACTIVITIES IN THE PACIFIC BASIN AND REGIONAL COOPERATION ON THE NUCLEAR FUEL CYCLE

Daniel P. Finn, Esq.

Pacific Ocean and island sites have been used since World War II for nuclear activities, including effluent discharges from nuclear facilities, sea dumping of packaged radioactive wastes, and testing of nuclear explosives. In the future, the amounts of radioactive wastes deliberately released into the Pacific Ocean may increase in connection with planned commercial-scale nuclear fuel reprocessing operations, recommencement of plutonium production for weapons purposes, and resumption of sea dumping of low level wastes. Proposed storage of spent nuclear fuel on Pacific island sites or disposal of high level wastes in the deep seabed of the Pacific could also expose the ocean to a risk of contamination by long-lived radionuclides. The consequences of all these activities should be assessed in practical terms -- their likely effects on the living marine resources of the Pacific and the economic development of the societies benefited by them; in terms of the legal principles which govern activities such as marine radioactive waste disposal that could pollute the marine environment; and in relation to current and future organizational arrangements that could achieve political resolution of outstanding international nuclear energy issues.

In press: Ocean Development and
International Law.

RADIOACTIVE WASTE DISPOSAL IN THE PACIFIC BASIN AND INTERNATIONAL COOPERATION ON NUCLEAR WASTE MANAGEMENT

Daniel P. Finn

This paper describes the international law and organization that has been created to control marine disposal of radioactive wastes, especially in the North Atlantic, and examines how these institutions could be applied to similar issues arising from nuclear waste storage and disposal activities in the Pacific. It also suggests that political resolution of disagreements about proposed nuclear waste management activities in the Pacific Basin could be achieved through some form of internationalization of the nuclear fuel cycle, perhaps organized on a regional basis.

In press:
"Emerging Marine Economy of the
Pacific." C. Gopalakrishnan, ed.
Proceedings of Conference of Marine
Technology Society, Honolulu,
October 13-15, 1981.

THE STATE - LANDLORD OR ENTREPRENUER?

Merrie G. Klapp

The 1970s were a period of turmoil as governments in both developed and less developed countries tried to take the lead in national oil development. While governments shifted from the role of landlord to that of entrepreneur, forming state oil companies, multinational corporate and private domestic industry groups blocked the way by switching from renters to political opponents. By the close of the decade, state oil companies had carved themselves a niche in multinational oil company operations but had been forced to make room there for other national industry groups as well. This article compares the process in Norway, Britain, Indonesia, and Malaysia, and tries to explain evidence that states in less developed countries (LDCs) gained more from multinational oil companies than did those in developed countries. Contrasting hypotheses concerning the ability of LDCs to harness multinational companies are explored. An alternative hypothesis is generated that relies on domestic rather than just international factors to explain the relatively greater gains of LDCs; it holds implications for the state's roles as landlord or entreprenuer. This explanation is contrasted with arguments that the coherence or strength of domestic structures explains relative state gains in the international economy.

DEEP OCEAN MINING

Robert W. Knecht

The existence of immense quantities of manganese nodules on the sea floor of the deep ocean has been known for several decades. While development of pilot-scale technology and assessment of the economic potential of these deposits has gone forward, commercialization of seabed mining still appears a long way off. Key factors in this delay are:

(1) depressed long-term outlook for metal prices;
(2) continuing uncertainty in the legal framework which will govern deep seabed mining beyond the limits of national jurisdiction.

While an upturn in the global economic picture could improve the climate for seabed mining, the negative position toward the recently completed Law of the Sea treaty being taken by the United States and several other industrial nations could further complicate the establishment of the legal certainty needed for this new industry to go ahead.

OUR NATION AND THE SEA - ONCE AGAIN TIME FOR CONSIDERED ACTION

Robert W. Knecht

The article calls attention to the danger of premature, piece-meal governmental action in the wake of the U.S. decision not to sign the recently completed Law of the Sea (LOS) Treaty. Early proclamation of a 200-mile, exclusive economic zone by the U.S. could foreclose later more comprehensive approaches. Given the interrelationships between many of the LOS issues as well as their coupling to a number of pending domestic issues such as the conduct of offshore oil and gas exploitation and fisheries management, the creation of a new study commission, patterned after the earlier "Stratton Commission," is suggested.

IMPLICATIONS OF THE LAW OF THE SEA CONVENTION FOR U.S. OCEAN POLICY

Robert W. Knecht and Robert E. Bowen

Although it participated actively in its development, the United States has made it clear that it will not sign the recently completed Law of the Sea Treaty. The President has indicated that while most of the Treaty's provisions are consistent with U.S. interests, one portion -- that dealing with seabed mining -- is objectionable in a number of fundamental ways. The paper examines the implications of the U.S. decision on three sets of U.S. interests; (1) as a seapower and maritime nation; (2) as a large coastal state (broad continental shelves, rich fishing grounds); and (3) as a nation concerned with environmental quality and conservation.

The study reaches these conclusions:

(1) Given the magnitude and diversity of U.S. ocean interests, the U.S. will be significantly affected by the LOS Convention even if it does not become a party to the treaty in the foreseeable future.
(2) Over time, the Convention will have its most important impact on international law (and consequently, on the U.S.) to the extent that its provisions serve as the authoritative guide to a consistent and uniform practice of coastal states.
(3) Domestic action, probably involving legislation, will be required to take advantage of parts of the Convention consistent with our interests, for example, establishment of an EEZ.
(4) The U.S. will also find it necessary to take action to deal with the potential adverse effects of certain other LOS provisions, such as those dealing with marine scientific research and seabed mining.
(5) Reviewing and deciding upon appropriate courses of action in connection with these issues will be a major preoccupation of ocean interests in the 1980s.
(6) Such reviews must take into account the status of the LOS Convention in international law and the possible reaction of other countries to the U.S. decision not to sign the treaty.

(7) Given that certain of the LOS-triggered issues are politically volatile and mingled with existing coastal and ocean management problems (e.g., the expansion of the U.S. territorial sea), the creation of a "study commission" is suggested as a means of reaching a national consensus on them.

STATE vs. NATIONAL INTERESTS IN AN EXPANDED TERRITORIAL SEA

Robert W. Knecht and William E. Westermeyer

The recently adopted Law of the Sea (LOS) Convention contains a provision allowing coastal nations to adopt 12-mile territorial seas. Already 104 nations (of a total of 137 coastal nations) have claimed territorial seas of 12 miles or wider. The paper discusses the factors which, in the opinion of the authors, could cause the U.S. to broaden its territorial sea from the present 3 miles to 12 miles within the next half-dozen years or so. The state-federal ocean use and resource management issues that will be raised by such a move are reviewed and options for dealing with the jurisdictional issues are developed. Given the political and economic volatility of these issues and their complexity, the use of a broadly representative and well-staffed study commission to formulate a course of action is suggested.

OCEAN DUMPING OF SEWAGE SLUDGE: THE TIDE TURNS FROM PROTECTION TO MANAGEMENT

William Lahey

This article examines the legal and institutional issues associated with ocean dumping of municipal waste in the United States. As background to the legal analysis the environmental problems associated with sewage sludge dumping are summarized. The legislative and regulatory history of ocean dumping in the United States evinces that a protective policy toward the ocean prevailed during the 1970s. This protective policy, however, has recently been brought into question by the courts, regulatory agencies and advisory groups. This article examines the basis for these views and describes the resulting changes in policy. Finally, the future of ocean dumping is evaluated; the legal limitations to changes in ocean dumping policy are examined and the economic, technical, and environmental issues which should be considered when the ocean dumping regulatory program is revised are discussed.

THE COMPARATIVE COSTS OF DEEP-SEA AND NEAR-SHORE OCEAN DUMPING

Thomas M. Leschine and James M. Broadus

The comparative costs of proposed deepwater ocean dumping for municipal sewage sludge are explored in terms of present near-shore ocean dumping activities in the New York Bight. The comparative internal costs of near-shore and distant site options are related to the reduction in external costs required to move the dumping operations to a more distant site. The relative internal costs associated with alternative sites are measured by three different approaches. These measures approximate short-run variable transportation costs, short-run total transportation costs, and long-run total transportation costs, respectively. A comparison among results suggests the ratio of total internal cost for the proposed deepwater dumpsite to that for the near-shore site to be about four. Long-run transportation cost estimates, as measured by a transportation cost algorithm developed for the U.S. EPA, are quite sensitive to transport vessel size and sludge thickness, suggesting that clear

tradeoffs exist in future capital investment strategies for sludge processing and disposal, if distant ocean dumpsites are to be used. Estimates of short-run total transportation cost reported by all current dumpers in the region suggest a minimum efficient scale for ocean sludge dumping in the 0.5 -1.0 million cubic meter per year range.

ALLOCATION OF AQUACULTURE RESOURCES

Susan Peterson

Production of food by aquaculture involves many dubious assumptions about man and nature. Descriptions of aquaculture systems abound; almost without exception, they bear on the technological aspects of development and ignore discussion of the feasibility of development. Between the two questions of "Can it be done?" and "Should it be done?" are a series of questions about methods used to choose and establish aquaculture systems. This paper discusses allocation questions associated with development of commercial aquaculture systems, including property rights, land tenure, work group formation, and product distribution.

ELEMENTS IN EVALUATING SUCCESS AND FAILURE IN AQUACULTURE PROJECTS

Richard B. Pollnac, Susan Peterson and Leah J. Smith

This chapter uses examples from aquaculture development projects in Latin America and Africa to describe general requirements of aquaculture development, decision points in a development project, and evaluations of success and failure by the personnel from funding agencies. It concludes that successful aquaculture development depends upon careful consideration of economic, sociocultural, scientific, and technological factors, and that aquaculture projects can, under appropriate circumstances, make a substantial contribution to the well-being of people in the developing world.

I PAESAGGI TURISTICI DELLA SARDEGNA (SARDINIA'S TOURIST LANDSCAPES)

Richard L. Price

The coast of Sardinia has undergone radical change in the last twenty years as parts of the littoral have developed as important centers for international tourism. This development has resulted in a dichotomy of coastal tourism and tourist landscapes marked by local tourism on one hand and international or continental tourism on the other hand. The historical origins of these two coastal uses in Sardinia is identified and the differences between them are described. A typology of tourist settlements is offered as a means of further discriminating among types of coastal tourism within the two major categories.

LAW OF THE SEA: HOW WILL IT AFFECT MARINE RESEARCH?

David A. Ross

After eight years of negotiations, the United Nations adopted a treaty on the Law of the Sea on April 30, 1982. The international agreement will come into force when it is ratified by 60 nations, and will become law for all countries, including those that do not sign the treaty. The U.S. is not expected to sign the treaty. The United States, with Venezuela, Turkey and Israel, opposed the treaty, and seventeen nations (including most of the

Soviet Bloc) abstained in the formal vote.

INTERNATIONAL MARINE SCIENCE: AN OPPORTUNITY FOR THE FUTURE

David A. Ross and Michael C. Healy

The style and techniques used by marine scientists to conduct research in foreign waters are clearly entering a period during which major changes will be necessary if many research activities are to continue. In the United States and other developed countries, marine scientists are experiencing decreased funding for research and a reduction in the size of academic oceanographic fleets. Furthermore, since the United States has declined adoption of the Law of the Sea Treaty, uncertainties and complexities for U.S. scientists in the international arena have increased. One technique that could counteract the curtailment of research that these events suggest and also lead to improved international opportunities in marine research is to foster new or improved mechanisms for cooperation among marine scientists, institutions and governments.

HOW THE LAW OF THE SEA TREATY WILL AFFECT U.S. MARINE SCIENCE

David A. Ross and John A. Knauss

The Law of the Sea Treaty will clearly affect the way U.S. marine scientists operate in about 40 percent of the ocean. The matter will be made even more complex by the apparent intention of the Reagan Administration to remain outside the treaty.

FUNDING CRISIS IN THE MARINE MINERALS INDUSTRY

Kurt Michael Shusterich

Both business and government recognize the high costs and benefits associated with the development of an ocean mining industry. The large amount of capital required for that development has led to the formation of several consortia to carry out exploration, mining, and processing research. It has been estimated that four United States-based companies have already spent approximately $200 million to investigate various aspects of nodule mining. Industry plans in the mid-1970s estimated that by the late 1980s the total investment would reach $3 billion. If recent discoveries of polymetallic sulfide ore deposits on ocean spreading centers can be commercially mined as well, that figure may be several times larger by the turn of the century. Recent trends in the United States, however, indicate that the industry is in a stagnant period and may not get beyond the first stages of development in its current form.

This paper examines the nature of the deep seabed mining industry and some of the reasons why its development has been dramatically slowed over the past three to four years.

THE FUTURE OF THE OCEAN MINING INDUSTRY IN THE STATE OF CALIFORNIA: MANAGEMENT AND PLANNING DECISIONS

Kurt Michael Shusterich

The goal of this paper is to present information about the deep seabed mining industry that may assist planning and management decisions in California regarding that industry's potential role in the state. A brief overview of the industry and relevant aspects of the Law of the Sea (LOS) Treaty is presented, followed by an outline of policy concerns the state should consider in evaluating its current and future approach to the deep ocean mining industry. The final part of the paper suggests the need for a small task force to further study the issues raised in the paper.

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WHOI Contribution No. 5249.

MINING THE DEEP SEABED:
A COMPLEX AND INNOVATIVE INDUSTRY

Kurt Michael Shusterich

High costs, technological uncertainties
and a complicated legal regime have led
representatives from U.S. ocean mining
companies to exert pressure on Administra-
tion and congressional leaders in Washington
to help them secure a favorable operating
environment. These efforts have complicated
U.S. relations with many other countries at
the Third United Nations Conference on the
Law of the Sea (UNCLOS III). UNCLOS III
received wide publicity last year because
of the Reagan administration's review
process and the insistence of the Group of
77 that the conference be concluded by 30
April. The eventual U.S. vote against the
treaty was welcomed (and influenced) by
representatives of the deep seabed mining
industry. This article examines the
nature, concerns, and interests of this
important new industry, and analyzes the
merits and disadvantages of an interim
period of unilateral deep seabed mining
legislation.

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WHOI Contribution No. 5042.

RESOURCE MANAGEMENT AND THE OCEANS:
THE POLITICAL ECONOMY OF
DEEP SEABED MINING

Kurt Michael Shusterich

The exploitation of valuable resources
beyond the boundaries of national
sovereignty has provoked international
confrontations and made clear the need for
some form of resource management control.

In particular, the potential for mining the
deep seabed for strategic minerals has
raised several legal, political, and
economic questions. It is likely that the
management structure of the International
Seabed Authority will influence the nature
of technology transfers, revenue-sharing
arrangements for other resource commons,
and the overall relationship between the
developed and developing nations of the
world for at least the next two decades.

This book addresses various questions
concerning the management of the global
commons by focusing on the case of deep
seabed mining. The author analyzes the
major issues and developments associated
with U.S. and international laws on marine
policy and resource management, at the same
time pointing to the broader range of
political implications that may influence
exploitation of other resource commons.

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Colorado, May 1982, 344 pp.

Supported by: Pew Memorial Trust;
NOAA Grant NA80AA-D-00077 (E/L-1);
Marine Policy and Ocean Management
Program.

UTILIZATION OF MARINE RESOURCES IN
DEVELOPING COASTAL STATES: A COOPERATIVE
INTERNATIONAL MARINE AFFAIRS PROGRAM

Maynard Silva, James Broadus,
David A. Ross and Robert Knecht

If developing coastal countries are to
develop their ocean resources in a timely
and efficient manner, they will require
assistance from developed coastal states.
The best form of assistance is probably the
transfer of managerial and technical
expertise/technology. This paper describes
a program designed to provide such
assistance being developed by the Marine
Policy and Ocean Management Program of the
Woods Hole Oceanographic Institution.

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AQUACULTURE DEVELOPMENT IN LESS
DEVELOPED COUNTRIES: SOCIAL, ECONOMIC,
AND POLITICAL PROBLEMS

Leah J. Smith and Susan Peterson, eds.

The twelve chapters in this book can be
considered in two parts: those which
generalize about aquaculture development
and those which use case study material to

describe problems associated with development. In the first category, the authors describe aquaculture development in general, discuss the nutritional value of aquaculturally produced products, discuss problems of allocation of resources, compare capture fishing and farming experiences as they may be applied to aquaculture, and finally suggest a system for evaluating aquaculture development. The second category includes articles about development in Latin America, Mexico, Costa Rica, Sierra Leone, Israel, and Egypt.

PITFALLS IN THIRD WORLD AQUACULTURE DEVELOPMENT

Leah J. Smith and Susan Peterson

Aquaculture – raising marine or freshwater animals and plants in controlled environments – has been suggested as a partial solution to world food problems. Development projects in the Third World have been supported by international, national, and private agencies interested in improving the quality and quantity of food throughout the world. Some of these projects have failed: some because of inadequate attention to social, economic, and political factors; others because of inadequate understanding of the mechanics of fish culture. This paper describes the pitfalls developers may expect in the development process.

LAW OF THE SEA AND UNDERWATER CULTURAL RESOURCES

David R. Watters

The Convention on the Law of the Sea, the culminating document of the Third United Nations Conference on the Law of the Sea, received favorable votes from 130 States in April 1982. The United States voted against approval. Articles 149 and 303, which address archaeological and historical objects found in various ocean zones, are compromise measures with ambiguous texts that are subject to interpretation. Archaeologists generally, not simply underwater archaeologists, should be concerned with these provisions because they could set an unfortunate precedent for future international negotiations involving cultural resources, and because they may apply to inundated prehistoric sites as well as shipwrecks.

RELATING OCEANOGRAPHY TO ANTILLEAN ARCHAEOLOGY: IMPLICATIONS FROM OCEANIA

David R. Watters

Cultural adaptations of the prehistoric Antillean peoples were necessarily based upon orientation toward the sea as well as land. Serious investigation of the maritime aspects of such adaptations is now beginning to complement terrestrial components that were emphasized in previous archaeological research. Wide-ranging interactions between human populations and marine and estuarine environments are better understood in another insular region, Oceania. Methodologies used, data gathered, and interpretations made there are potentially useful for guiding research in the Antilles. Other problems seem to be peculiar to the Antilles, however, and differences between these areas are as important as the similarities.

UNCLOS III: THE "ARCHAEOLOGICAL OBJECTS" ARTICLES

David R. Watters

The resumed Tenth Session of the Third United Nations Conference on the Law of the Sea (UNCLOS III) produced the Draft Convention on the Law of the Sea in which two articles (149 and 303) specifically address submerged cultural objects. The articles seem to have been written with shipwrecks firmly in mind but other categories of cultural materials also may be within their purview. Various ocean zones are defined in the Draft Convention.

Archaeological and historical objects are subject to coastal state or international jurisdiction depending on the zone in which they are submerged. The "archaeological objects" articles raise legal and political issues that should be of concern to underwater archaeologists.

UNITED STATES ANTARCTIC POLICY
AND THE REAGAN ADMINISTRATION

William E. Westermeyer

United States Antarctic policy and the strategy with which to implement it has remained relatively constant since the signing of the Antarctic Treaty in 1959. Two factors contribute to the belief that a re-evaluation of U.S. Antarctic policy at this time is desirable: (1) since the early 1970s, interest in the resource potential of Antarctica has been growing, and (2) the values and goals of the present administration are in several significant ways different from those of previous administrations. Antarctic policy has not yet emerged as an important concern of the Reagan administration, but this could change appreciably if mineral resource exploitation in Antarctica becomes feasible. This essay identifies the traditional U.S. interests in Antarctica and evaluates these interests in light of the growing resource potential of the continent and the values and goals of the Reagan administration.

GRADUATE STUDENTS

Abstracts of papers or theses submitted in 1982 by graduate students of the Woods Hole Oceanographic Institution Doctoral Degree Program and the Woods Hole Oceanographic Institution/Massachusetts Institute of Technology Joint Program in Oceanography/Oceanographic Engineering. Other papers authored or coauthored by graduate students are included in the departmental sections. Students are indicated by an asterisk in the Author Index.

GRADUATE STUDENTS

EVOLUTION AND HYBRIDIZATION IN THE RADIOLARIAN GENERA Theocorythium AND Lamprocyclas

Colin Baker

The changes in morphological variability within fossil populations of planktonic protists provide insight into the processes occurring during events of morphological change. Evolution in the radiolarian genera Theocorythium and Lamprocyclas is documented biometrically in Pliocene and Pleistocene core material from the equatorial Pacific and Indian Oceans. The patterns of morphological change in Theocorythium within a single Pacific core could be interpreted as indicating the in situ evolution of T. trachelium from T. vetulum via intermediate forms during the Pleistocene. In fact, this is not the case, and consideration of biogeographic data supports an interpretation of migration coupled with extensive hybridization and introgression. Analyses of evolutionary change in Theocorythium and the closely related genus Lamprocyclas during the Pliocene suggest that hybridization is significant as a factor in the production of new species. Evolutionary models and phylogenetic analyses should consider that barriers to gene flow may vary significantly with time and permit the exchange of genetic information between populations formerly considered as reproductively isolated.

DEVELOPMENT OF THE HEPATOPANCREAS IN EARLY STAGES OF THE AMERICAN LOBSTER Homarus americanus

Patricia Biesiot

Details of morphological changes in the hepatopancreas of developing lobster embryos and larvae were examined by light microscopy. Both paraffin (6 um) and plastic (2 um) sections were prepared from laboratory reared animals in the intermolt stage. Yolk was intercalated among the hepatopancreatic tubules of embryos and Stage I larvae but was not observed in older stages. All cell types found in adults, embryonic (E-cells), fibrillar (F-cells), secretory (B-cells), and resorptive (R-cells), were observed in each of the four larval stages but not all types were seen in embryos. A brush border was present. Complexity of the hepatopancreas increased with development, most spectacularly in the fourth stage. The R-cells of lobsters younger than Stage IV did not contain the large number of lipid vacuoles typical of this cell type. But

these cells were morphologically distinct from F-cells which had a larger nucleus and a fibrous appearance.

HISTOLOGICAL CHANGES ASSOCIATED WITH DEVELOPMENT OF THE HEPATOPANCREAS IN LARVAE OF THE AMERICAN LOBSTER (Homarus americanus)

Patricia Biesiot

This study provides details of morphological changes in the hepatopancreas of developing lobster larvae using light microscopy. Laboratory hatched larvae were raised communally and fed frozen adult Artemia ad lib. Hepatopancreatic tissue from embryos (obtained three days before the sibling hatches) and from intermolt larvae (molt stage C) was fixed in Deitrich's fixative, embedded in paraffin, sectioned at 5 um, and stained with hematoxylin and eosin.

Yolk was intercalated among the hepatopancreatic tubules of the embryos and the first stage larvae but was not observed in the older larvae. During development, the complexity of the hepatopancreas increased. The lumen of the hepatopancreatic tubules was small in the embryo, large in the first stage, and then gradually decreased in the older larval stages. Fourth stage larvae had the smallest diameter lumen but the thickest cells making up the tubule wall.

The hepatopancreas is composed of four cell types: embryonic (E-cell), fibrillar (F-cell), secretory (B-cell), and resorptive (R-cell). All cell types were found in each of the four larval stages but only E- and R-cells were observed in the embryos examined. F-cells may in fact be present in late embryos, perhaps in low numbers so that none were seen in this series of sections or they may develop later on. The absence of B-cells can be explained by assuming that they develop from F-cells after the stimulation of the feeding process; embryos have not yet fed. The R-cells of late embryos and of larval stages one, two, and three contained only a few small vacuoles rather than the large number typical of older stages. But these cells were morphologically distinct from the F-cells which had a larger nucleus and a fibrous appearance. Only in stage four, which represents the transition from a planktonic existence to benthic habits, did

the R-cells have the characteristic frothy appearance. The brush border was observed in the four larval stages although it was not very distinct in stage one. The presence of R-cells, generally considered to be resorptive or storage cells, in the late embryos is puzzling unless they perform some other function as well.

ABYSSAL BENTHONIC FORAMINIFERA AND THE CARBONATE SATURATION OF SEA WATER
AND
A BENTHONIC FORAMINIFERAL CARBONATE SATURATION HISTORY FOR THE CAPE VERDE BASIN FOR THE LAST 550,000 YEARS

Mary L. Bremer

The distribution of certain Atlantic Ocean benthonic foraminifera is most consistently correlated with the degree of saturation of seawater with respect to calcium carbonate. The relative abundance of cibicidids, miliolids, Uvigerina and Globocassidulina subglobosa increases in saturated water and the relative abundance of Nuttlaides umbonifera increases in undersaturated water. It is suggested that this is a response of living benthonic foraminifera. Using this relationship it is possible to recognize changes in the "paleosaturation" of deep and bottom waters from fossil deep-sea benthonic foraminifera.

The deepest water in the western Atlantic is barred from flowing into the eastern Atlantic by topographic barriers such as the Walvis Ridge and the Mid-Atlantic Ridge. The major conduits of the deepest and most dense water into the eastern Atlantic are the fracture zones on the ridge such as the Romanche, Chain and Vema Fracture Zones. The carbonate saturation of the Cape Verde Basin is very sensitive to the hydrography at these sill depths in the western Atlantic.

The four cores studied range from 2471-4696 m. They are relatively isolated from the influx of terrigenous detritus and have low sedimentation rates which vary between 0.5 and 0.7 cm/1000 years. They do not show the Atlantic Ocean glacial, low carbonate-interglacial, high carbonate cycles seen in other higher sedimentation rate cores. This supports the contention of Broecker et al. (1958), Needham et al.

(1969), Ruddiman (1971), Hays and Perruzza (1972) and Damuth (1977) that the cycles are produced by masking of carbonate by terrigenous detritus.

The glacial-interglacial variability (in particular, increases in U. peregrina during glacial times) observed in higher latitude cores (Streeter and Shakleton, 1979; Schnitker, 1979; Corliss, in preparation) was not observed.

A carbonate saturation history for the Cape Verde Basin for the last 550,000 years based on benthonic foraminifera shows that undersaturation in the Cape Verde Basin was great or greater than it is today at 120,000-180,000 yr. B.P., 280,000 yr. B.P, 375,000-425,000 yr. B.P. and 525,000 yr. B.P. The inferred carbonate saturation changes could have been produced by a decrease of less than $1^\circ C$ at the sill depths of the Romanche, Chain and Vema Fracture Zones. The increases in undersaturation are not correlative with upward migrations of what is reinterpreted here to be the undersaturation biofacies at the Rio Grande Rise in the southwestern Atlantic (Lohmann, 1978) and in the southeastern Indian Ocean (Corliss, 1979). In both the southeastern Indian Ocean and in the Cape Verde Basin, the greatest increase in undersaturation occurs between 375,000-425,000 yr. B.P. These upward migrations are interpreted to represent shoaling of the deep water-bottom water transition.

FREE SURFACE FLOW THROUGH SALT MARSH GRASS

Roger W. Burke

A numerical model is presented for predicting the vertical variation of flow through and above large obstructions, with special emphasis on tidally inundated marsh grass. Because the grass may extend through the depth of the water column, thus affecting the stress at the air-water interface, the model has the capability to extend the calculations into the overlying air layer. The model is able to compute the simultaneous vertical distribution of both horizontal velocity components.

A scaling analysis of the governing momentum equations for typical salt marsh geometrics shows that the acceleration terms are generally negligible compared to the vertical transport terms. With this approximation, the momentum equation reduces to a local force balance between

the vertical momentum transport, surface pressure gradient, and vegetative drag force. A review of previous obstructed flow models solving this equation reveals that these models are generally unsuited to the purposes of this study, primarily because of an inability to provide an a priori parameterization for the vertical turbulent momentum transport, thus motivating the development of a different approach.

The two equation $k-\varepsilon$ technique parameterizes the turbulent stress using a turbulent diffusivity scheme, in which the turbulent length and velocity scales are determined from differential transport equations for the turbulent kinetic energy $(\check{k})$ and viscous dissipation (ε), thus allowing for the influence of diffusion on the turbulent scales, as well as the presence of more than one characterizing length scale. Modifications of the low Reynold's number form of the model (Jones and Launder, 1972, 1973) account for the additional force and turbulent energy flux caused by obstructions. The resulting model equations are solved using a finite control volume technique.

Model predictions compare favorably with a variety of analytical and experimental results for a variety of cases, including non-obstructed open channel and Couette flow, wind tunnel studies of flow through circular cylinders, a water flume study of flow through plastic strips, and field studies of flow through bean and corn crops. The model coefficients are held fixed in all comparisons, demonstrating the predictive abilities of the model for obstructed flow processes.

A study of free surface flow properties conducted in Great Sippewissett Marsh, in Falmouth, Massachusetts, provided the context for an application of the model to tidally inundated marsh grass. The measurements taken include marsh topography, wind speed and direction, water elevation at the marsh boundary, and vertical profiles of horizontal velocity at a number of locations within the marsh grass study area. The observed and predicted velocity profiles are in generally good agreement, although it was necessary to adjust the values of the grass density, which were not measured independently.

Dimensional analysis shows that the obstructed flow processes are generally dependent on three parameters, relating to the grass density (a), grass height (h_g), and the relative importance of wind stress to surface pressure. Under many conditions, the dimensionless grouping $C_d h_g a$ where C_d is the drag coefficient, is the only relevant parameter governing obstructed flows. Sensitivity studies demonstrate the relationships between the governing parameters and the vertical distribution of various variables, including velocity, kinetic energy, and dissipation.

THE SPATIAL AND TEMPORAL ABUNDANCE PATTERNS OF CHAETOGNATHS IN THE WESTERN NORTH ATLANTIC OCEAN

Jerry Cheney

Zooplankton samples were collected with the MOCNESS in the upper 1000 m of the western North Atlantic Ocean on six cruises during the period from August 1975 to November 1977. The samples were used to study the geographic, vertical and seasonal abundance patterns of twenty-one chaetognaths.

Errors associated with net sampling, such as avoidance, mesh selection, patchiness, and subsampling, did not appear to greatly affect the observed abundance patterns.

Observed vertical distributions were similar to those previously reported for these species. No diel vertical migrations were detected, but ontogenetic migrations were observed for meso- and bathypelagic species. Spatial and temporal variations in vertical distribution appeared to be related to variations in size frequency distributions coupled with ontogenetic migrations rather than behavioral responses to environmental conditions.

Nine species were significantly more abundant in the Northern Sargasso Sea, seven were more abundant in the Slope Water, two showed no significant differences and three were too rare for analysis. Seasonal abundance patterns were detected only in the Northern Sargasso Sea. The seasonal and geographic abundance patterns were most likely related to variations in food and temperature.

Gulf Stream rings provide quasi-experimental sites for study of the factors regulating abundance patterns of chaetognaths.

THE DEVELOPMENT OF NONLINEAR SURFACE AND INTERNAL WAVE GROUPS

Teresa K. Chereskin

The development of nonlinear surface and internal wave groups is investigated. Surface wave evolution was observed in an unusually long wave channel as a function of steepness and group length. Dissipation and frequency downshifting were important characteristics of the long-time evolution. The amplitude and phase modulations were obtained using the Hilbert transform and specified as an initial condition to the cubic nonlinear Schrodinger equation, which was solved numerically. This equation is known to govern the slowly varying complex modulation envelope of gravity waves on deep water. When dissipation was included, the model compared quite well with the observations. Phase modulation was used to interpret the long-time behavior, using the phase evolution of exact asymptotic solutions as a guide. The wave groups exhibited a long-time coherence but not the recurrence predicted by the inviscid theory.

An oceanic field study of the generation of groups of large amplitude internal waves by stratified tidal flow over a submarine ridge indicates that the large amplitude and asymmetry of the topography are critical in determining the type of flow response. The calculated Froude numbers, response length scale and duration differ markedly between the two phases of the tide due to the asymmetry.

DAMPING ESTIMATION, RESPONSE PREDICTION AND FATIGUE CALCULATION OF AN OPERATIONAL SINGLE PILE PLATFORM

Michael F. Cook

A comparison between predicted and measured damping controlled dynamic response of an operational single pile platform (AMOCO's South Marsh Island Block 33B platform) is presented. In the predictive analysis, a finite element model of the structure and a theoretical assessment of damping phenomena are combined with a response prediction method which utilizes the principle of reciprocity of ocean waves. The result is a versatile expression for the estimation of the dynamic response fatigue life of a platform in a directionally spread sea. In addition, the data analysis performed on wind, wave and response time histories, recorded in March 1980, is carefully described. A method is presented which uses biaxial accelerometer data to infer platform modal orientations and to estimate wave spreading. Finally, modal natural frequencies and damping ratios are estimated using the Maximum Entropy Method (MEM) of spectral analysis. Good agreement between predicted and estimated response characteristics is attained.

URANIUM AND THORIUM ISOTOPE CONCENTRATIONS IN FORAMINIFERAL CALCITE

Margaret L. Delaney and Edward A. Boyle

Uranium and thorium isotope activities were measured by isotope dilution alpha spectrometry in four late Pleistocene and Holocene foraminiferal calcite samples. Sample cleaning methods were utilized to separate calcite tests from contaminating clay and surface oxide coatings. The maximum concentration of lattice bound uranium is 0.023 ppm (10×10^{-9} moles U/mole Ca), consistent with the lowest reported value, 0.025 ppm [1]. $^{230}Th/^{234}U$ activity ratios in samples cleaned as described above are much greater than one, indicating that the cleaning methods used do not effectively remove ^{230}Th from the surface of the calcite. The upper limit for lattice bound ^{232}Th is 0.039 ppm (17×10^{-9} moles Th/mole Ca).

In press: Earth and Planetary Science Letters.

PARTICLE PATHS IN GULF STREAM RINGS

William K. Dewar

A Lagrangian analysis of a numerical Gulf Stream Ring was conducted, the primary goal of which was to understand how the particle trajectories of a slowly evolving vortex satisfy Eulerian dynamic constraints. An approximation to the Lagrangian streakfunction in the vicinity of the Ring was obtained by an applicaton of a formula appropriate to permanent form, steadily propagating Eulerian streamfunctions. The accuracy of this streakfunction was verified by a series of advection-diffusion experiments. A cross check between the dynamically consistent streaklines and those computed in earlier studies of radially symmetric, kinematic ring models revealed that the general characteristics of the particle paths from both studies were similar. In detail, however, they were somewhat different. In particular, the location of the stagnation point and

the bearing of the critical streakline, both of which define the ring trapped zone, did not match, primarily because of the dispersion field of the dynamic ring. As a consequence, the volume of fluid able to invade the dynamic ring trapped zone is enlarged, and the origins of that fluid are brought into line with the path of ring center, as compared to the positions in line with the ring flanks suggested by the kinematic studies. With respect to satellite observations, the picture of particle flow as depicted by the dynamic ring model represents an improvement over that of the kinematic studies; however, it is suggested that ageostropic or diabatic effects will be necessary in future models of sea surface temperature.

WIND-GENERATED EQUATORIAL KELVIN WAVES OBSERVED ACROSS THE PACIFIC OCEAN

Charles C. Eriksen, Martin B. Blumenthal, S. P. Hayes and P. Ripa

Sea level fluctuations during 1978-1980 at equatorial Pacific islands separated by as much as one quarter of the earth's circumference are coherent at periods of 1-6 weeks with phases implying eastward propagation. Eastward speeds are 16 ± 7.5 higher than expected for a linear first baroclinic mode Kelvin wave (based upon hydrography). Zonal winds in the western Pacific exhibit variation on meridional scales comparable to those of equatorial ocean baroclinic motions. Roughly one quarter of sea level variance in the 1-6 week period range can be explained by local zonal wind alone. The observed admittance magnitude, 0 (0.1 cm sea level per $(m/s)^2$ zonal wind pseudostress), and phase lag (a few days, sea level lagging wind) can be accounted for in a linear model of baroclinic equatorial Kelvin waves generated by a crudely idealized wind patch of 100 km zonal scale. Zonal winds at the equator excite, among other things, low mode Kelvin waves which are recognizable 0(10000 km) to the east of the forcing.

In press: Journal of Physical Oceanography.

OBSERVED CIRCULATION AND INFERRED SEDIMENT TRANSPORT IN HUDSON SUBMARINE CANYON

Frances L. S. Hotchkiss

Velocity and temperature time series from Hudson Submarine Canyon and hydrographic surveys of seven canyons of the Middle Atlantic Bight indicate that the effects of storms, tides, and incoming internal waves are intensified in submarine canyons. Storms with strong eastward and westward wind stress were found to cause strong upwelling and downwelling through the upper layers of Hudson Canyon. Stormforced upwelling also caused strong down-canyon flows at the canyon floor.

Internal waves were found to be concentrated in the canyon head and near the floor, in agreement with theoretical predictions. Slope water apparently circulates slowly through the outer part of the canyon and is mixed in nearfloor layers which could be caused by breaking internal waves.

Internal tides are generated at the floor in the central part of the canyon. Oscillations at tidal frequencies dominate the near-floor velocity field below the thermocline, and are accompanied by high-frequency spikes that may be nonlinear interface waves propagating on the top of the bottom mixed layer. A numerical model was used to calculate mixing in the canyon's bottom boundary layer caused by an unstable density gradient during flood tide.

Energetic internal wave activity is apparently responsible for sediment sorting in the canyon head; the internal waves become more energetic as the sediment grain size increases. Below the thermocline, the tidal oscillations vary in amplitude with the phases of the moon; the observed deposition of mud can easily occur during weeks of low velocity.

HELIUM ISOTOPE GEOCHEMISTRY OF VOLCANIC ROCKS: IMPLICATIONS FOR MANTLE HETEROGENEITY AND DEGASSING

Mark D. Kurz

The concentrations and isotopic compositions of helium have been measured in a number of mantle derived oceanic basalts. The goal of this research is to use the helium isotopic systematics to constrain the nature and origin of mantle heterogeneity in the oceanic mantle.

Studies of helium partitioning in mid-ocean ridge basalt (MORB) glass, performed by crushing and melting in vacuo, show that a significant fraction of the helium resides within vesicles. Measured concentrations are therefore a function of original helium content, magmatic history, vesicle size and quantity, and grain size analyzed. The helium solubility inferred from the results is 3.7×10^{-4} cc STP/g-atm), which is significantly higher (by a factor of 5) than the enstatite value (Kirsten, 1968) most often used in the literature. Concentrations obtained from basaltic phenocrysts and glasses suggest that helium behaves as an incompatible element with respect to olivine, clinopyroxene, and plagioclase.

Diffusion rates for helium in basaltic glass (in the temperature range 125-400°C), determined using the method of stepwise heating, yielded an activiation energy of 19.9 ± 1 Kcal/mole and $\ln D_0 = -2.7 \pm .6$ (cgs units). Extrapolation of these results to ocean floor temperatures (0°C) gives a diffusivity of $1.0 \pm .6 \times 10^{-17}$ cm^2/sec, indicating that diffusion is an insignificant mechanism for helium loss from fresh basaltic glasses.

The diffusion and partitioning studies suggest that these processes will not alter the helium isotopic ratios in basaltic melts. Therefore, the isotopic composition of the oceanic mantle can be inferred by extracting the helium from basaltic glasses and phenocrysts.

A survey of the helium isotopic ratios in MORB glasses from all over the mid-ocean ridge system shows that there is considerable variation; the ^{3}He/^{4}He ratios range from 6.5 to 14.2 X atmospheric. The results from a number of oceanic island basalts show even more variability, with the ^{3}He/^{4}He ratios ranging from 5.0 X atmospheric (for alkali islands such as Gough and Tristan da Cunha) to 31.9 X atmospheric (for Loihi Seamount). The regional variability, and the correlations with ^{87}Sr/^{86}Sr can best be explained by the presence of three distinct reservoirs in the mantle which mix with one another. The three mantle source regions are believed to be 1) the depleted source for normal MORB (with ^{3}He/^{4}He ~8.4 X atmospheric), presumed to be in the upper mantle; 2) an undepleted mantle reservoir with ^{3}He/^{4}He > 8.4 X atmospheric; and 3) a recycled oceanic crust reservoir with ^{3}He/^{4}He < 8.4 X atmospheric. A model for mantle structure that is consistent with the observations is proposed and discussed in light of the geophysical data.

^{3}He concentrations for the different mantle reservoirs are inferred from the measurements, and suggest that the present-day ^{3}He flux, and the ^{3}He in MORB glasses, is ultimately derived from the lower mantle. Consideration of the ^{3}He flux, available ^{3}He/^{36}Ar measurements, and the atmospheric ^{36}Ar inventory, shows that present-day degassing rates are insufficient to generate the atmospheric argon. It is suggested that an episode of more rapid mantle outgassing occurred in the past.

SPRING MIGRATORY SYNCHRONY OF SALMONID, CATOSTOMID, AND CYPRINID FISHES IN RIVIÉRE Á LA TRUITE, QUEBEC, CANADA

W. Linn Montgomery, Stephen D. McCormick, Robert J. Naiman, F. G. Whoriskey and G. A. Black

During May-June 1980 and June-July 1982, six fish species exited Riviére á la Truite, a major tributary of the lower Moisie River, Quebec, in highly synchronized emigrations. Species included: longnose sucker (Catostomus catostomus), white sucker (C. commersoni), lake chub (Couesius plumbeus), juvenile sea lamprey (Petromyzon marinus), Atlantic salmon (Salmo salar) parr and smolt, and anadromous brook trout (Salvelinus fontinalis). In 1980, emigration for all species except the lamprey began on 27 May and ended by 9-11 June; lamprey movements began on 4-5 June and peaked on 10 June. A similar but slightly later pattern occurred in 1982. Onset of the runs in each year coincided with declining water levels and discharge. Results indicate that species of widely different niches have similar migratory patterns in response to strong changes in stream environment.

In press: Canadian Journal of Zoology.

THE DYNAMICS OF UNSTEADY STRAIT AND SILL FLOW

Lawrence J. Pratt

The dynamics of steady and unsteady channel flow over large obstacles is studied analytically and numerically in an attempt to determine the applicability of classical hydraulic concepts to such flows. The study is motivated by a need to

understand the influence of deep ocean straits and sills on the abyssal circulation.

Three types of channel flow are considered: nonrotating one dimensional (Chapter 2); semigeostrophic, constant potential vorticity (Chapter 3); and dispersive, zero potential vorticity (Chapter 4). In each case the discussion centers around the time-dependent adjustment that occurs as a result of sudden obtrusion of an obstacle into a uniform initial flow or the oscillatory upstream forcing of a steady flow over topography.

For nondispersive (nonrotating or semigeostrophic) flow, nonlinear adjustment to obstacle obtrusion is examined using a characteristic formulation and numerical results obtained from a Lax-Wendroff scheme. The adjustment process and asymptotic state are found to depend upon the height of the obstacle b_0 in relation to a critical height b_c and a blocking height b_b. For $b_0 < b_c < b_b$, isolated packets of nondispersive (long gravity or Kelvin) waves are generated which propagate away from the obstacle, leaving the far field unaffected. For $b_c < b_0 < b_b$, a bore is generated which moves upstream and partially blocks the flow. In the semigeostrophic case, the potential vorticity of the flow is changed by the bore at a rate proportional to the differential rate of energy dissipation along the line of breakage. For $b_b < b_0$ the flow is completely blocked.

Dispersive results in the parameter range $b_0 < b_c$ are obtained from a linear model of the adjustment that results from obstacle obtrusion into a uniform, rotating-channel flow. The results depend on the initial Froude number f_d (based on the Kelvin wave speed). The dispersive modes set up a decaying response about the obstacle if $F_d < 1$ and (possible resonant) lee waves if $F_d > 1$. However, the far-field upstream response is found to depend on the behavior of the nondispersive Kelvin modes and is therefore nil.

Nonlinear steady solutions to nondispersive flow are obtained through direct integration of the equations of motion. The characteristic formulation is used to evaluate the stability of various steady solutions with respect to small disturbances. Of the four types of steady solution, the one in which hydraulic control occurs is found to be the most stable. This is verified by numerical experiments in which the steady, controlled flow is perturbed by disturbances generated upstream. If the topography is complicated

(contains more than sill, for example), then controlled flows may become destabilized and oscillations may be excited near the topography.

The transmission across the obstacle of energy associated with upstream-forced oscillations is studied using a reflection theory for small amplitude waves. The theory assumes quasi-steady flow over the obstacle and is accurate for waves long compared to the obstacle. For nonrotating flow, the reflection coefficients are bounded below by a value of 1/3. For semigeostrophic flow, however, the reflection coefficient can be arbitrarily small for large values of potential vorticity. This is explained as a result of the boundary-layer character of the semigeostrophic flow.

TRANSFORMATIONS OF CAROTENOIDS IN THE OCEANIC WATER COLUMN

Daniel J. Repeta

In an effort to understand the more general mechanisms and rates of pre-depositional reactions that transform organic matter, the types and relevant time scales of reactions that transform carotenoid pigments in the oceanic water column were studied.

In the present study, a model was constructed for organic matter cycling that consisted of three parts: 1) the synthesis of carotenoid pigments by phytoplankton in the euphotic zone, 2) consumption and metabolism of some fraction of these pigments by heterotrophic organisms, and 3) removal of metabolic by-products to the sediments by large particle (e.g. fecal pellet) transport. The model separates particulate matter into reservoirs according to the degradation processes that have occurred since synthesis. The goal is to sample these particulate reservoirs, determine the compositional differences between them, and construct a mechanistic pathway for the transformations that occur as material is transferred between reservoirs.

Suspended particulate matter collected in the surface waters of Buzzards Bay, Massachusetts, and the Peru upwelling region has a carotenoid distribution reflecting the phytoplanktonic source of the material. The carotenoid distribution of sediment trap samples collected in these areas was dominated by transformation products. Fucoxanthin, the primary

carotenoid of marine diatoms, typically constituted 77-100 percent of the total fucopigments in suspended particulate matter. In sediment trap samples this pigment constituted only 4-85 percent of the total. The remaining 15-96 percent of the pigments consisted of the fucoxanthin transformation products: free alcohols (2-94 percent), dehydrates (0-6 percent), and opened epoxides (0-19 percent).

Postulated transformation products were synthesized to determine the structure of isolated compounds. Simultaneously, iodine catalyzed photoisomerization of fuco-pigments was tested as a potential method for the unambiguous identification of carotenoids requiring only the nanogram amounts of material typically found in samples.

Preliminary results suggest that carotenoid esters are hydrolyzed at a rate determined by the turnover of primary productivity. The dehydrated and epoxide opened degradation products of fucoxanthin represent products of transformation reactions that operate over much longer time scales (0.1-10 yr). Dehydration and epoxide opening are not significant water column transformations, but are important in surface sediments. A transformation pathway of ester hydrolysis > dehydration > epoxide opening > further dehydration is proposed for fucoxanthin. Preliminary evidence for a parallel transformation sequence for structurally similar carotenoids is also presented.

BIOCHEMICAL CHANGES ASSOCIATED WITH LARVAL DEVELOPMENT IN THE LOBSTER, Homarus americanus

Glenn C. Sasaki

The aim of this study was to correlate changes in major biochemical constituents with larval development. Lobsters, hatched in the lab from captured egg bearing females, were held at $21\pm1^{\circ}C$ and fed frozen adult Artemia. The larvae were molt staged by live mount microscopic examinations of various spines of the tail region. Classification was based, with modifications, on the criteria of Aiken (1980); with the following stages being defined: A, B, C, D_0, D_1', D_1'', D_1''', D_2, D_3.

Dry weight was measured after a distilled water rinse and lyophilization.

Ash was weighed after a 475° C 12-hour exposure. Protein and carbohydrate were colorimetrically determined with the BioRad and phenol-sulfuric acid assays respectively. The BioRad assay was modified by prior sample treatment with 0.1 N NaOh at 80° C for 30 minutes followed by neutralization with HC1. Chitin was determined from the lipid extraction residue after successive 2 percent HCl and 1 percent NaOH treatments. Lipid analyses are currently underway.

The dry weight, ash, and carbohydrate values all were correlated with the molting cycle. Minimum values for percent dry weight (13-16 percent) were observed immediately after hatching and molting, rising to a maximum value (19-21 percent) prior to each molt.

Sudden increases were noted in percent ash after the hatch and at each molt. Percent ash was maximum (26-34 percent) during intermolt declining to a minimum (15-20 percent) prior to each molt. Gross ash values also reflected this pattern, indicating an actual loss of ash prior to each molt. Such a pattern may be homologous to the calcium resorption prior to molting that occurs in juveniles and adults.

Carbohydrate levels, which were minimal (4 percent ashfree) during intermolt, rose to a maximum (6-7 percent ashfree) just prior to the molt and then declined after the molt. This may indicate the use of carbohydrate as an energy substrate during the molt recovery period.

Gross protein values showed a general rise through development which did not correlate with the molt cycle, though the greatest rates of increase appeared to occur during intermolt. On a percent basis the protein levels dropped with development from a high of 72-77 percent (ashfree) to a low of 40 percent (ashfree). This latter value appears low and may indicate an interference with the assay method.

Gross chitin levels also increased with development but did not show strong trends with the molting cycle. Percent values showed a minimum immediately after hatching which quickly rose and then remained somewhat level (8-11 percent ashfree) until the fourth stage when an increase became evident (15 percent ashfree).

These preliminary results indicate that changes in biochemical constituents of the larval stages of the American lobster are related to both molting and developmental sequences.

ESTIMATES OF CRUSTAL TRANSMISSION LOSSES USING MLM ARRAY PROCESSING

Edward K. Scheer

The MLM data adaptive array processor, as an estimator of the frequency/wavenumber function of a multidimensional random process, is used to determine crustal transmission losses. Results obtained with a set of seismic refraction data from the ROSE experiment are presented. A method implemented in the TL determination for correcting errors in the amplitude of the estimates, due to the MLM bias that occurs when using sparse arrays, is introduced.

THE DYNAMICS OF MEAN CIRCULATION ON THE CONTINENTAL SHELF

Ping-Tung Peter Shaw

Mean long-isobath drift of the order 5 cm/sec has been observed on several continental shelves, e.g. in the Middle Atlantic Bight and in the Weddell Sea. A theoretical model is developed to explore the driving mechanism of this mean circulation. In the model, the velocity field is decomposed into a depth-independent bottom geostrophic component and a thermohaline component relative to the bottom. The latter can be calculated from the density field, and the former is described by a parabolic equation which expresses the tendency to balance vorticity between bottom stress curl and vortex stretching. The near-bottom flow field is studied both analytically and numerically under forcing by wind, deep ocean flow, and long-isobath density differences.

Model solutions are derived for circulations over a shelf/slope topography driven by wind stress, wind stress curl, and deep ocean currents. The resulting flow patterns show strong dependence on the topography. Over the continental slope, large bottom depth variation suppresses the flow driven by local forcing and insulates the slope region from circulations on the shelf and in the deep-ocean. Geochemical observations on the continental shelf and slope support the argument that the flow on

the upper slope below the thermocline is weak.

Under the condition of a vertically homogeneous layer below the thermocline, near-bottom density advection is mainly caused by the bottom geostrophic velocity field. Using the parabolic vorticity equation together with a density equation, circulations driven by coastal buoyancy flux and surface cooling are investigated. In the mid-shelf region, away from the coast and the shelf break, the density field is governed by Burgers' equation, which shows longshore self-advection of density perturbations and the formation of front with strong density gradient in the longshore direction. A dense water blob moves in the direction of Kelvin wave propagation. The direction is reversed for the movement of a light water blob. In the near-shore region, the light river water at the bottom is also self-advected in the direction of Kelvin wave propagation. For a heavy density anomaly at the coast, the initial movement is offshore, and the accumulation of dense water in the mid-shelf region leads to long-isobath propagation of density perturbations, similar to the case of a dense water blob. This theory sheds light on the bottom water movements in the Adriatic Sea, the Antarctic Continent, and the Middle Atlantic Bight.

The model solutions are applied to the flow on the western North Atlantic shelf. Southwestward flow is produced near the coast by the self-advection of river water in winter and spring. The southwestward long-isobath propagation of thermal fronts caused by winter cooling contributes significantly to the mean circulation over the mid-shelf. It is suggested that density-driven current is an important component of the near-bottom mean circulation in the Middle Atlantic Bight in spring and summer.

VERTICAL FLUX, ECOLOGY AND DISSOLUTION OF RADIOLARIA IN TROPICAL OCEANS: IMPLICATIONS FOR THE SILICA CYCLE

Kozo Takahashi

Radiolarians which settle through the oceanic water column were recovered from three stations (western Tropical Atlantic-Station E, central Tropical Pacific-P_1 and Panama Basin-PB) using PARFLUX sediment traps in moored arrays at several depths. The taxonomic diversities of the radiolarian assemblages in the sediment traps were very high. A total of

420 taxa, including 23 newly identified taxa, were found at the three stations; of these, 208 taxa were found at station E. The polycystine radiolarians generally reach the sea floor with little change in abundance or species composition, although slight skeletal dissolution occurs throughout their descent. The phaeodarian radiolarians, on the other hand, are largely dissolved within the water column; only a few species reach the sea-floor and these dissolve rapidly at the sediment-water interface. Most radiolarian skeletons sink as individuals through deep water columns without being incorporated into large biogenic aggregates. Because significant numbers of nassellarian and phaeodarian species are deep-water dwelling forms the diversity index of radiolarians increases with increasing depth in the mesopelagic zone.

The vertical flux of the total radiolarians arriving at the trap depths (in x 10^3 individuals/m^2/day) ranged from 16-24 (E), 0.6-17 (P_1), and 29-53 (PB). Of these on the average 25 percent and 69 percent of the total radiolarian flux is transported by Spumellaria and Nassellaria, respectively, while 5 percent is carried by Phaeodaria. The measured SiO_2 content of the skeletons averaged 91, 98 and 71 percent of measured weight for Spumellaria, Nassellaria and Phaeodaria, respectively. The supply of radiolarian silica (mg SiO_2/m^2/day) to each trap depth ranged from 2.5-4.0 (E), 0.9-3.2 (P_1), and 5.7-10.4 (PB). The Radiolaria appear to be a significantly large portion of the SiO_2 flux in > 63 μm size fraction and thus play an important role in the silica cycle. When the radiolarian fluxes at the three stations are compared with Holocene radiolarian accumulation rates in the same areas it became apparent that several percent or less of the fluxes are preserved in the sediments in all cases and the rest is dissolved on the sea-floor. Estimated excess Si which is derived from SiO_2 dissolution on the sea-floor is fairly small relative to advective Si in the western North Atlantic and thus it appears to be insignificant to show any deviation in a simple mixing curve of deep water masses.

Weight, length, width, projected area and volume of 58 radiolarian taxa were measured. The density contrast of radiolarians, relative to seawater, generally falls between 0.01 and 0.5 g/cm^3. The sinking speed of 55 radiolarian taxa, measured in the laboratory at 3°C, ranged from 13 to 416 m/day. Despite the wide variety of morphology between the species, sinking speeds were best correlated with weight/shell among all the possible combinations of the examined variables. The estimated residence times of these taxa in the 5 km pelagic water column ranged from 2 weeks to 14 months. Large phaeodarians reached the water-sediment interface relatively quickly and ultimately dissolved on the sea floor. Small-sized taxa dissolved en route during sinking.

The standing stock of 26 examined abundant taxa is on the order of 1 to 100 shells/m^3. Total radiolarian standing stock ranges from about 450 shells/m^3 at Stations P_1 and E to 1200 shells/m^3 at Station PB. The rate of production of total Radiolaria is calculated to be 77 to 225 shells/m^3/day. The turnover time for these species ranges from several days to one month depending on the species and the assumption of the depth interval used for the estimation.

INSTABILITIES AND RADIATION OF THIN, BAROCLINIC JETS

Lynne D. Talley

Oceanic fluctuations are dependent on geographical location. Near intense currents, the eddy field is highly energetic and has broad meridional extent. It is likely that the energy arises from instabilities of the intense current. However, the meridional extent of the linearly most unstable modes of such intense jets is much narrower than the observed region of energetic fluctuations. It is proposed here that weaker instabilities, in the linear sense, which are very weakly trapped to the current, may be the dominant waves in the far field.

As a preliminary problem, the (barotropic) instability of parallel shear flow on the beta plane is discussed. An infinite zonal flow with a continuous cross-stream velocity gradient is approximated with segments of uniform flow, joined together by segments of uniform potential vorticity. This simplification allows an exact dispersion relation to be found. There are two classes of linearly unstable solutions. One type is trapped to the source of energy and has large growth rates. The second type are weaker instabilities of the shear flow which excite Rossby waves in the far field: the influence of these weaker instabilities extends far beyond that of the most unstable waves.

The central focus of the thesis is the linear stability of thin, two-layer, zonal jets on the beta plane, with both horizontal and vertical shear. The method used for the parallel shear flow is extended to the two-layer flow. Each layer of the jet has uniform velocity in the center, bordered by shear zones with zero potential vorticity gradient. The velocity in each layer outside the jet is constant in latitude. Separate linearly unstable modes arise from horizontal and vertical shear. The energy source for the vertical shear modes is nearly all potential while the source for the horizontal shear modes is both kinetic and potential. The most unstable waves are tightly trapped to the jet, within two or three deformation radii for small but nonzero beta. Rossby waves and baroclinically unstable waves (in the presence of vertical shear) exist outside the jet because of a nonzero potential vorticity gradiant there. Weakly growing jet instabilities can force these waves when their phase speeds and wavelengths match. In particular, westward jets and any jets with vertical shear exterior to the jet can radiate in this sense. The radiating modes influence a large region, their decay scales inversely proportional to the growth rate. Two types of radiating instability are found: (1) a subset of the main unstable modes near marginal stability and (2) modes which appear to be destabilized neutral modes. Westward jets have more vigorously unstable radiating modes.

Applications of the model are made to the eddy field south of the Gulf Stream, using data from the POLYMODE settings along 55° W and farther into the gyre at MODE. The energy decay scale and the variation of vertical structure with latitude in different frequency bands can be roughly explained by the model. The lower frequency disturbances decay more slowly and become more surface intensified in the far field. These disturbances are identified with the weak, radiating instabilities of the model. The higher frequency disturbances are more trapped and retain their vertical structure as they decay, and are identified with the trapped, strongly unstable modes of the jet.

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INSTRUMENTATION FOR THE MEASUREMENT OF PHYTOPLANKTON PRODUCTION

Craig D. Taylor, John J. Molongoski and Steven E. Lohrenz

Automated instrumentation is described that performs time-course incubation experiments directly in situ where natural conditions of temperature, light, hydrostatic pressure, etc., can be maintained. The sampler incubation device (SID) obtains a 1-liter sample from the water column and simultaneously introduces an appropriate radiotracer. During subsequent in situ incubation, 50 ml subsamples are withdrawn from the main incubating sample at equally spaced time intervals and preserved for laboratory analysis. Representative time course experiments employing the SID revealed non-linear carbon uptake within 0.5-1.0 h, emphasizing that end point analyses of even short duration can lead to large errors in estimating phytoplankton production rates. Studies of the rapid fluctuation in phytoplankton activity resulting from large order, cloud-induced variations in light intensity, and the application of cellular fractionation methods for measuring the intracellular distribution of newly fixed carbon illustrated the utility of instrumental time course techniques for studying phytoplankton physiology and community metabolism in situ.

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SEISMICITY AND STRUCTURE OF THE OROZCO TRANSFORM FAULT FROM OCEAN BOTTOM SEISMIC OBSERVATIONS

Anne M. Trehu

Seismic waves generated by sources ranging from 2.7 kg shots of TNT to magnitude 5 earthquakes are studied in order to determine the seismic activity and crustal structure of the Orozco transform fault. Most of the data were collected by a network of 29 ocean bottom seismometers (OBS) and hydrophones (OBH) which were deployed as part of project ROSE. In Chapter II, the tectonic setting, bathymetry and teleseismic history of the Orozco Fracture Zone are summarized. Because teleseismic earthquake locations are too imprecise to define the present plate boundary and magnetic anomaly data are too sparse to resolve the recent tectonic history, more questions are raised than are answered. Chapter III contains an examination of the transfer function between seafloor motion and data records by the MIT OBS. Hypocentral parameters for 70 earthquakes are presented in Chapter IV. Because of the large number of stations in the ROSE network, the epicentral locations, focal depths and source mechanisms are determined with a precision unprecedented

in marine microseismic work and clearly
delimit the present active plate boundary.
In Chapter V, several data sources provide
information on lateral variations in the
crustal and upper mantle velocity structure
in the transform region: incident angles
and azimuths from shots and earthquakes
observed at MIT OBS; travel times and
amplitudes from lines of small shots
recorded at WHOI OBH; and travel times from
large shots throughout the region. The
effect of the proposed structures on the
results of Chapter IV is also discussed.
In the last chapter, the above results are
combined to define the present plate
boundary and speculate on the history of
the present configuation.

AUTHOR INDEX

* student
+ deceased